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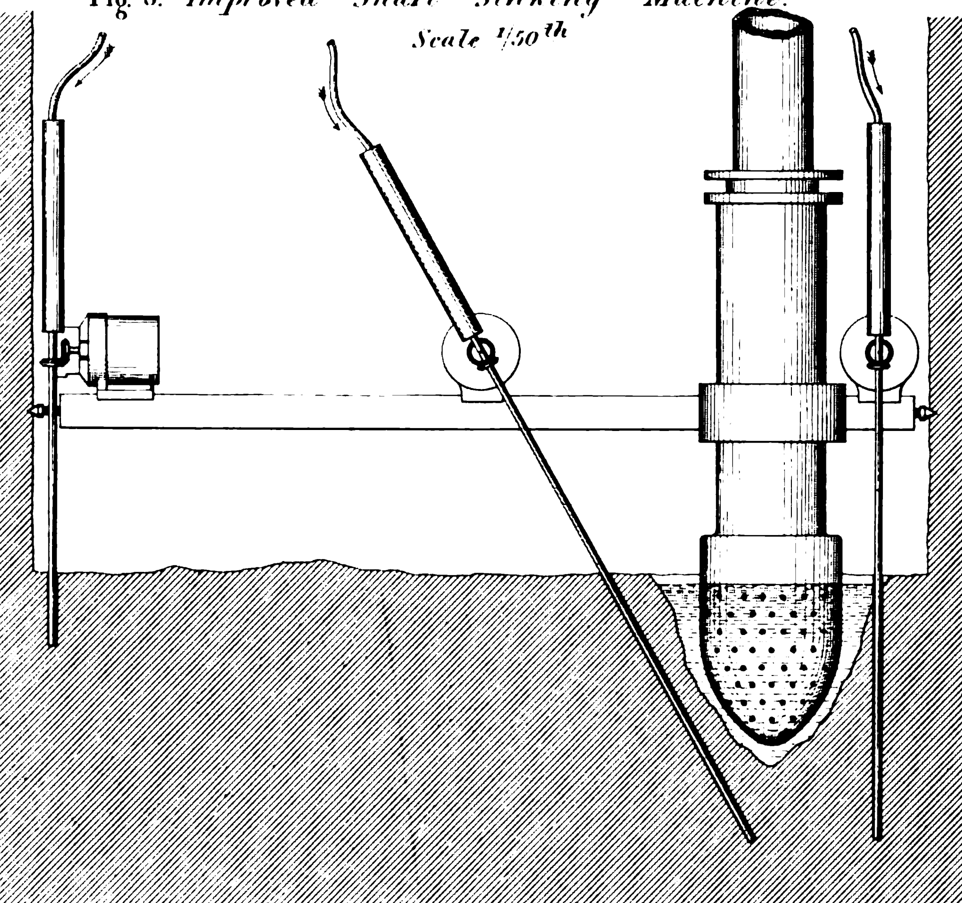
Fig. 8. Improved Shaft-Sinking Machine.

Scale 1/50th



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PROCEEDINGS.

1875.

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Robert Stephenson, F.R.S., (*deceased* 1859)	*London.*

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Birmingham and Midland Bank, Birmingham.

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WILLIAM P. MARSHALL.

Assistant Secretary.—Alfred Bache,

Institution of Mechanical Engineers,

81 *Newhall Street, Birmingham.*

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LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1875.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1874. Abernethy, James, 2 Delahay Street, Westminster, S.W.
1875. Adams, Thomas, Granby Row, Manchester.
1848. Adams, William Alexander, Walford Manor, near Shrewsbury.
1859. Adamson, Daniel, Engineering Works, Hyde Junction, near Manchester.
1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester.
1861. Addenbrooke, George, Messrs. Addenbrookes Smith and Pidcock, Rough Hay Furnaces, Darlaston, near Wednesbury; and Greenhill, Wombourne, near Wolverhampton.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.
1870. Alexander, Alfred, Corinium Iron Works, Cirencester.
1847. Allan, Alexander, Kenilworth Villa, South Cliff, Scarborough.
1875. Allan, George, Savile Street Engineering Works, Sheffield.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1870. Alley, John, Locomotive Superintendent, Moscow and Razan Railway, Moscow: (or care of Messrs. Carruthers and Alley, 88 Bath Street, Glasgow.)
1865. Alleyne, Sir John Gay Newton, Bart., Butterley Iron Works, Alfreton.
1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.
1871. Allport, Howard Aston, Bestwood Coal and Iron Co., 40 Elm Avenue, Nottingham.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

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1856. Anderson, John, LL.D., F.R.S.E., 22 Victoria Road, Old Charlton, London, S.E.
1856. Anderson, William, Messrs. Eastons and Anderson, Erith Iron Works, Erith, London, S.E.
1862. Angus, Robert Nicoll, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. Appleby, Charles Edward, Renishaw Colliery, near Chesterfield.
1867. Appleby, Charles James, Messrs. Appleby Brothers, Emerson Street, Southwark, London, S.E.
1873. Appleby, Henry, Locomotive Superintendent, Monmouthshire Railway, Newport, Monmouthshire.
1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid.
1874. Archer, David, General Manager, Messrs. Brown Marshalls and Co., Britannia Railway Carriage and Wagon Works, Birmingham.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.
1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.
1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.
1873. Arnold, David Nelson, Manager, Midland Wagon Works, Lander Street, Birmingham.
1857. Ashbury, James Lloyd, M.P., 66 Grosvenor Street, London, W.
1873. Ashbury, Thomas, Managing Director, Ashbury Railway Carriage and Iron Works, Openshaw, Manchester.
1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.
1875. Atkinson, Edward, Assistant Manager, Messrs. Fletcher Jennings and Co.'s, Lowca Engine Works, Whitehaven. (*Life Member.*)
1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Arundel Street, Sheffield.
1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.
1874. Ayton, Frederick, Messrs. Ayton and Co., Eagle Brewery, Bishopbriggs, Glasgow.

1872. Bagshaw, Walter, Victoria Foundry, Batley.
1865. Bagshawe, John J., Thames Steel Works, Sheffield.

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1865. Bailey, John, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.

1860. Bailey, Samuel, Mining Engineer, Perry Barr, Birmingham.

1872. Bailly, Philimond, 49 Rue du Pont Neuf, Brussels.

1866. Baines, William, London Works, Soho, near Birmingham.

1873. Baird, George, Messrs. Baird, Iron Works, St. Petersburg; and 5A Cork Street, Burlington Gardens, London, W.

1866. Baker, Samuel, Engine and Boiler Works, 22 Oil Street, Liverpool.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1870. Barber, Thomas, Jun., Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, Westfield, Surbiton, Kingston-on-Thames.

1860. Barclay, John, Bowling Iron Works, near Bradford.

1860. Barker, Paul, Old Park Iron Works, Wednesbury.

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.

1866. Barnard, Clement, 4 Billiter Square, London, E.C.

1862. Barrow, Joseph, Barr Hill Mount, Pendleton, Manchester.

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury.

1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W.

1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth.

1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Elm Tree Villa, Smallheath, Birmingham.

1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.

1869. Beattie, William George, Locomotive and Carriage Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1859. Beck, Edward, Dallam Forge, Warrington; and Palmyra Square, Warrington. (*Life Member.*)

1873. Beck, William Henry, 139 Cannon Street, London, E.C.

1875. Beckwith, John Henry, Engineer to Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.

1865. Bell, Charles, Messrs. Palmer and Bell, Agricultural Engineers, Taganrog, South Russia; and 9 Croom's Hill Grove, Greenwich, S.E.

1858. Bell, Isaac Lowthian, M.P., F.R.S., Clarence Iron Works, Middlesbrough; and Harlsey Hall, Northallerton.

1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.

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1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.

1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.

1873. Bentley, John Greenwood, Westfield Cottage, Penistone, near Sheffield.

1875. Berry, Francis, Messrs. Francis Berry and Sons, Calderdale Iron Works, Sowerby Bridge.

1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.; and Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Manor Hill, Birkenhead.

1874. Bewick, Thomas John, Mining Engineer, 4 Broad Sanctuary, Westminster Abbey, Westminster, S.W.; and Haydon Bridge, near Carlisle.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1866. Birkbeck, John Addison, 8 Acklam Terrace, Newport Road, Middlesbrough.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1875. Bisset, William Harvey, Board of Trade Surveyor, Custom House Arcade, Liverpool.

1870. Blair, John, Chief Locomotive Superintendent, Danish Government Railways, Aarhuus, Denmark.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 18 London Street, London, E.C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, near Warrington.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1872. Boistel, Georges, 11 Rue de Châteaudun, Paris.

1872. Bolton, Major Francis John, 4 Broad Sanctuary, Westminster Abbey, Westminster, S.W.

1869. Borrie, John, Zetland Buildings, Middlesbrough.

1862. Bouch, Thomas, 78 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1869. Boyd, William, Wallsend Slipway Co., Wallsend, near Newcastle-on-Tyne.

1875. Braconnot, Capt. Carlos, Chief Director and Engineer of the Marine Arsenal, Rio de Janeiro: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

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1873. Bradbury, Charles Jordan, Heaton Terrace, Bury Old Road, Cheetham Hill, Manchester.

1875. Bradley, Isaac, Manager, Ammunition Works, Ward End, Birmingham.

1854. Bragge, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield; and Shirle Hill, Sheffield.

1875. Braithwaite, Richard Charles, Manager, Old Park Iron Works, Wednesbury.

1854. Bramwell, Frederick Joseph, F.R.S., 37 Great George Street, Westminster, S.W.

1868. Breeden, Joseph, 157 Cheapside, Birmingham.

1875. Broadbent, Thomas, Chapel Hill Iron Works, Huddersfield.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)

1874. Brotherhood, Peter, Messrs. Brotherhood and Hardingham, 56 Compton Street, Goswell Road, London, E.C.; and 25 Ladbroke Gardens, Notting Hill, London, W.

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1847. Brown, James, Thornhill, Handsworth, near Birmingham.

1853. Brown, Ralph, Patent Shaft Works, Wednesbury.

1869. Browne, Benjamin Chapman, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1869. Browne, Walter Raleigh, Managing Director, Bridgwater Engineering Works, Bridgwater.

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 5 Ladbroke Square, Notting Hill, London, W.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W.

1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.

1872. Brunner, Henry, Messrs. John Hutchinson and Co.'s Alkali Works, Widnes; and Cliff House, Appleton, Widnes.

1865. Bryant, Frederick William, 6 Westminster Chambers, Victoria Street, Westminster, S.W.

1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.

1873. Buckley, Robert Burton, Assistant Engineer, Indian Public Works Department, Buxar, Bengal, India: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 23 Lower King Street, Manchester.

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1872. Bullock, Thomas, Jun., Messrs. Thomas Bullock and Sons, Button Manufacturers, Cliveland Street Works, Birmingham.

1870. Burgh, Nicholas Proctor, 80 Cornhill, London, E.C.

1874. Burn, William Edward, 21 Collingwood Street, Newcastle-on-Tyne.

1871. Burrows, James, Douglas Bank, Wigan.

1870. Bury, William, 5 New London Street, London, E.C.

1873. Bury, William Tarleton, Messrs. Bury and Co., Regent Steel Works, Sheffield.

1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.

1859. Butler, John, Stanningley Iron Works, near Leeds.

1859. Butler, John Octavius, Kirkstall Forge, near Leeds.

1873. Butterfill, Henry Holt, 213 Regent Street, Hull.

1871. Cabry, Charles, District Resident Engineer, North Eastern Railway, York.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.

1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.

1864. Campbell, David, 105 Eglinton Street, Glasgow.

1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.

1869. Campbell, James, Hunslet Engine Works, Leeds.

1860. Carbutt, Edward Hamer, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford.

1875. Cardozo, Francisco Corrêa de Mesquita, Messrs. Cardozo and Irmão, Pernambuco Engine Works, Pernambuco: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.) (*Life Member.*)

1869. Carpmael, Frederick, 31 Berners Street, Ipswich.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C.

1868. Carrington, Thomas, Jun., Mining Engineer, Kiveton Park Collieries, near Sheffield.

1874. Carrington, William T. H., 76 Cheapside, London, E.C.

1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.

1870. Carver, James, Messrs. Carver and Mosley, Lace-Bobbin and Carriage Works, Butcher Street, Nottingham.

1869. Caspersen, Hans William, Engineer, Danish Government Railway Service; 164 Rye Hill, Newcastle-on-Tyne.

1871. Chamberlain, Walter, Moor Green Hall, Moseley, near Birmingham.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.

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1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.

1869. Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1869. Clapham, Robert Calvert, Earsdon, near Newcastle-on-Tyne.

1866. Claridge, Thomas, Messrs. Claridge and Co., Phœnix Foundry, near Bilston.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan.

1859. Clark, George, Southwick Engine Works, near Sunderland.

1867. Clark, George, Jun., Southwick Engine Works, near Sunderland.

1862. Clark, James, Wellington Foundry, Leeds.

1867. Clark, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Rogers, Railway Foundry, Jack Lane, Leeds.

1869. Clarke, William, Messrs. Clarke Watson and Gurney, Victoria Works, South Shore, Gateshead.

1859. Clay, William, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and D 7 Exchange Buildings, Liverpool.

1875. Clayton, Charles, Soho Foundry, Preston.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1871. Cleminson, James, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1873. Clench, Frederick, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1866. Cleworth, Charles, District Locomotive Superintendent, East Indian Railway, Assensole, India.

1847. Clift, John Edward, Mayfield, Cheltenham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.

1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.

1854. Cochrane, John, 51 Queen's Gate Gardens, London, S.W.

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Coxlodge, Newcastle-on-Tyne.

1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, Ordnance Cotton Mill, Blackburn.

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1847. Coke, Richard George, Mining Engineer, Tapton Grove, Chesterfield.

1867. Coke, William Langton, District Engineer, Cape Government Railways, Port Elizabeth, Algoa Bay: (or care of William Sacheverell Coke, Brookhill Hall, near Alfreton.)

1874. Conyers, William, Engineer, Locomotive Superintendent, and General Manager, Otago Railways, Dunedin, Otago, New Zealand.

1875. Cooper, Frederick, Chief Engineer, H. M. Gun Carriage Department, Bombay.

1874. Cooper, William, Messrs. Gilbert and Cooper, Engineers and Iron Shipbuilders, Neptune Iron Works, Hull.

1848. Corry, Edward, 8 New Broad Street, London, E.C.

1875. Cotton, Francis Michael, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton.

1868. Coulson, William, Mining Engineer, Shamrock House, Durham.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1870. Cowen, George Roberts, Beck Foundry, Brook Street, Nottingham.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.

1869. Crossley, Louis J., Dean Clough Carpet Mills, Halifax.

1871. Crossley, William, Furness Iron and Steel Works, Askam, near Dalton-in-Furness, Lancashire.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.

1863. Crow, George, Messrs. R. Stephenson and Co.'s Works, Newcastle-on-Tyne.

1874. Curry, William, Locomotive Superintendent, Dublin and Drogheda Railway, Dublin.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.

1869. Daglish, John, Mining Engineer, Tynemouth, near North Shields.

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1866. Daniel, Edward Freer, Messrs. Thornewill and Warham's Iron Works, Burton-on-Trent; and 75 Branstone Road, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds; and 37 Camp Road, Leeds.

1872. Danson, Thomas James, 3 St. Nicholas Buildings, Newcastle-on-Tyne.

1865. Darby, Abraham, Treberfydd, Bwlch, Brecknockshire.

1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.

1873. Davey, Henry, Messrs. Hathorn Davis Campbell and Davey, Sun Foundry, Dewsbury Road, Leeds.

1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich.

1874. Davis, Alfred, Messrs. Hathorn Davis Campbell and Davey, Sun Foundry, Dewsbury Road, Leeds; and 4 Westminster Chambers, Victoria Street, Westminster, S.W.

1868. Davis, Henry Wheeler, 11 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Davy, Walter Scott, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Daw, Samuel, 5 Dock Chambers, Cardiff.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.

1861. Dawson, Benjamin, Engineer, Haswell Colliery, Fence Houses.

1869. Day, St. John Vincent, 166 Buchanan Street, Glasgow.

1874. Deacon, George Frederick, Borough Engineer, Municipal Offices, Dale Street, Liverpool.

1874. Deakin, Thomas, Sandon Street Engine Works, Broughton Road, Salford, Manchester.

1868. Dean, William, Great Western Railway, Locomotive Department, Swindon.

1866. Death, Ephraim, Albert Works, Leicester.

1858. Dees, James, Floraville, Whitehaven.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1872. Denton, John Punshon, 3 Vansittart Terrace, Coatham, Redcar.

1868. Derham, John J., Brookside, near Blackburn.

1875. Dickinson, William, Messrs. Eastons and Anderson, 65 Southwark Street, London, S.E.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1868. Dodman, Alfred, St. James's Iron Works, Lynn.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.

1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle.

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1873. Dove, George, Jun., Redbourn Hill Iron and Coal Co.'s Works, Frodingham, near Brigg.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Royal Exchange, Middlesbrough.

1874. Dredge, James, 37 Bedford Street, Strand, London, W.C.

1847. Dübs, Henry, Glasgow Locomotive Works, Glasgow.

1870. Dunlop, James Wilkie, 22 Leadenhall Street, London, E.C.

1857. Dunlop, John Macmillan, Holehird, Windermere.

1864. Dunn, Thomas Edward, Kurhurballee Collieries, Chord Line East Indian Railway, viâ Muddapur Junction, India; and The Cottage, Rusper, near Horsham.

1875. Durie, James, 7 Lancaster Avenue, Fennel Street, Manchester.

1860. Dyson, George, Saltburn-by-the-Sea.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1859. Eassie, Peter Boyd, Messrs. William Eassie and Co., Railway Saw Mills, Gloucester.

1858. Easton, Edward, Messrs. Eastons and Anderson, Grove, Southwark Street, London, S.E.; and 7 Delahay Street, Westminster, S.W.

1867. Easton, James, Mining Engineer, Nest House, Gateshead.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.

1866. Elce, John, Phœnix Iron Works, Jersey Street, Manchester.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham.

1870. Elsdon, Robert, 76 Manor Road, Upper New Cross, London, S.E.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1860. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.

1875. Elwell, Thomas, Jun., Engineer, Messrs. Varrall Elwell and Middleton's Works, 1 Avenue Trudaine, Paris.

1857. Evans, John Campbell, 8 Great George Street, Westminster, S.W.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1865. Evers, Frank, Cradley Iron Works, near Stourbridge.

1869. Eyth, Max, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.

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1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, Wellington Foundry, Leeds; and Goldsborough Hall, Knaresborough.

1869. Fairless, John, Forth Banks Engine Works, Newcastle-on-Tyne.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, Messrs. Hayward Tyler and Co.'s Works, 84 Upper Whitecross Street, London, E.C.; and 31 Wilberforce Road, Finsbury Park, London, N.

1872. Fearn, John Wilmot, Mining Engineer, 31 Devonshire Street, Chesterfield; and Newbold Road, Chesterfield.

1870. Ferguson, Henry Tanner, District Locomotive Superintendent, Great Indian Peninsula Railway, Egutpoora, near Bombay, India.

1854. Fernie, John, Bonchurch, Ventnor, Isle of Wight.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1872. Fidler, Edward, Platt Lane Colliery, Wigan.

1867. Field, Edward, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.

1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.

1868. Firth, Arthur, Leeds Iron Works, Leeds.

1868. Firth, Samuel, 16 York Place, Leeds.

1874. Firth, William, Burley Wood, Leeds.

1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Somerset and Dorset Railway, Highbridge, near Bridgwater.

1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Westbromwich.

1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1867. Fletcher, Lavington Evans, Chief Engineer, Association for the Prevention of Steam Boiler Explosions, 41 Corporation Street, Manchester.

1872. Flower, James J. A., Messrs. James Flower and Sons, Cape Town, Cape of Good Hope; and 9 America Square, Crutched Friars, London, E.C.

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

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1861. Forster, Edward, Messrs. Chance Brothers and Co.'s Glass Works, Spon Lane, near Birmingham.

1869. Forster, George Baker, Backworth, Newcastle-on-Tyne.

1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.

1861. Foster, Sampson Lloyd, 2 Prince's Place, Duke Street, St. James', London, S.W.; and Callipers Hall, Chipperfield, Rickmansworth, Herts.

1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1866. Fox, Charles Douglas, 5 Delahay Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1859. Fraser, John, 18 York Place, Leeds.

1852. Froude, William, F.R.S., Chelston Cross, Torquay.

1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., Director of Works and Public Buildings, 12 Whitehall Place, London, S.W.; and 12 Chester Street, Grosvenor Place, London, S.W.

1870. Garstang, James H., General Manager, Signal Construction Works, Monmouth Street, Bridgwater.

1867. Gauntlett, William Henry, 9 Grange Road, Middlesbrough.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1870. Gibson, John, Engineer, Ryhope Colliery, near Sunderland.

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1856. Gilkes, Edgar, Messrs. Hopkins Gilkes and Co., Tees Engine Works, Middlesbrough.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1867. Gooch, William Frederick, Vulcan Foundry, Warrington.

1869. Goodeve, Thomas Minchin, Goldsmith Buildings, Temple, London, E.C.

1875. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester.

1865. Göransson, Göran Fredrick, Steel Works, Gefle and Hägbo, Sweden.

1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1871. Gowenlock, Alfred Hargreaves, care of Messrs. Jessop and Co., Railway Contractors, 93 Clive Street, Calcutta.

1869. Grainger, James Nixon, Public Works Department, Chepank, Madras: (or care of G. N. Henton, Newport, Isle of Wight.)

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1865. **Gray**, John McFarlane, Board of Trade Steam Ship Surveyor, St. Katharine Dock House, London, E.

1870. Gray, Matthew, 106 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.

1870. Greaves, James Henry, Albert Buildings, Queen Victoria Street, London, E.C.

1861. Green, Edward, Jun., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.

1874. Greenwood, William Henry, 108 Stretford Road, Manchester.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1874. Grew, Nathaniel, 8 New Broad Street, London, E.C.

1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1860. Grice, Frederic Groom, Ansty's Lea, Torquay.

1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1873. Griffiths, John Alfred, Messrs. Griffiths Brothers and Co., Toowoomba Foundry, Ruthven Street, Toowoomba, Queensland: (or care of Thomas Griffiths, Higher Crumpsall, Cheetham Hill, Manchester.)

1874. Griffiths, John R., Manager, Ebbw Vale Co.'s Iron Works, Pontypool.

1870. Guilford, Francis Leaver, Messrs. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1863. Hackney, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1863. Hall, Joseph, Graz Iron Works, Graz, Styria, Austria.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1871. Hall, William Silver, Abbey Works, Nuneaton.

1871. Halpin, Druitt, Victoria Graving Docks, London, E.

1870. Hamand, Arthur Samuel, Stephenson Chambers, New Street, Birmingham.

1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham; and Leicester House, Kenilworth Road, Leamington.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Campinas, São Paulo, Brazil.

1870. Hannah, Joseph Edward, New Exchange Buildings, Middlesbrough.

1874. Harding, William Bishop, Beverley Iron and Wagon Works, Beverley.

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1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1873. Harman, Harry Jones, Engineer, Duke of Sutherland's Colliery, Brora, Sutherland.

1859. Harman, Henry William, Adelphi Hotel, John Street, Adelphi, London, W.C.

1873. Harris, Richard Henry, Malvern Link, Worcestershire.

1856. Harrison, George, Canada Works, Birkenhead.

1871. Harrison, Joseph Edward, Woodside Iron Works, near Dudley.

1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1865. Harrison, William Arthur, Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester.

1874. Hart, James, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1872. Hartnell, Wilson, Rodborough, Stroud, Gloucestershire.

1871. Hartness, John, Lloyd's Inspector, Wear Chain and Anchor Testing Works, Sunderland.

1872. Hassall, Henry Thomas, Messrs. Hassall and Singleton, Phœnix Foundry, Freeman Street, Birmingham.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)

1873. Hawkins, Charles W., Locomotive Superintendent, Great Indian Peninsula Railway, Byculla, Bombay.

1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.

1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.

1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.

1860. Head, John, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.

1873. Headly, Lawrance, Manager, Eagle Foundry, Mill Road, Cambridge.

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, 9 Rumford Place, Liverpool.

1864. Heathfield, Richard, Lion Galvanising Works, Wiggin Street, Icknield Port Road, Birmingham.

1875. Heenan, Richard Hammersley, Executive Engineer to the Bhawulpoor State, Bhawulpoor, India: (or care of Walter May, Suffolk Works, Berkley Street, Birmingham.)

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1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool.

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1864. Hetherington, William Isaac, 2 Green Bank, Moss Lane East, Manchester.

1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.

1872. Hewlett, Alfred, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1871. Hick, John, M.P., Mylton Hall, Whalley, near Blackburn.

1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.

1870. Higson, John, Mining Engineer, St. George's Chambers, Albert Square, Manchester.

1873. Hildebrandt, John Albert Reinhold, Bow Chambers, 55 Cross Street, Manchester.

1871. Hill, Alfred C., Royal Exchange, Middlesbrough; and Newcomen Street, Coatham, Redcar.

1867. Hill, Henry Walker, 51 Hampden Street, Nottingham.

1873. Hilton, Franklin, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.

1869. Hind, Henry, Central Engineering Tool Works, Queen's Road, Nottingham.

1874. Hird, Holmes, Engineer, Messrs. Bass and Co.'s Brewery, Burton-on-Trent.

1870. Hodges, Petronius, Yorkshire Steel and Iron Works, Penistone, near Sheffield.

1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.

1852. Holcroft, James, Norton, near Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1871. Holiday, Joseph, Union Foundry, Cutler Heights, near Bradford.

1865. Holliday, John, Meyrick House, Hill Top, Westbromwich.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, Royal Insurance Buildings, Leeds.

1867. Holt, William Lyster, 7 Great Winchester Street Buildings, London, E.C.

1867. Homer, Charles James, Mining Engineer, Chatterley Iron Works, Tunstall, near Stoke-upon-Trent.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.

1856. Hopkinson, John, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

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1874. Hopkinson, John, Jun., D.Sc., Manager, Lighthouse and Optical Department, Messrs. Chance Brothers and Co.'s Glass Works, Spon Lane, near Birmingham.

1867. Hopper, William, Machine Works, Moscow: (or care of Thomas Hopper, 5 South Frederick Street, Edinburgh.)

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1868. Horsley, Thomas, King's Newton, near Derby.

1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury,

1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.

1867. Horton, Thomas Ellwood, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.

1875. Hosgood, Thomas Hopkin, Manager, Plymouth Iron Works, Merthyr Tydvil.

1873. Hoskin, Richard, 2 Alliance Chambers, George Street, Sheffield.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.

1861. Howell, Joseph Bennett, Brook Steel Works, Brookhill, Sheffield.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1873. Hughes, Henry, Falcon Iron Works, Loughborough.

1871. Hughes, Joseph, Parton Hæmatite Iron Works, near Whitehaven.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.

1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.

1870. Hunstone, William Henry, Springfield Iron Works, Salford, Manchester.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1856. Hunt, Thomas, 38 Nottingham Street, Sheffield.

1874. Hunt, William, Jun., Messrs. William Hunt and Sons, Alkali Works, Lea Brook, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1864. Hutchinson, Edward, Hurworth, Bournemouth.

1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta: (or care of Rev. H. M. C. Hyde, 184 The Grove, Camberwell, London, S.E.) (*Life Member.*)

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1867. Inglis, William, Messrs. Hick Hargreaves and Co.'s, Soho Iron Works, Bolton.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.

1866. Ireland, William, care of Jonathan Ireland, Edward Street, Broughton Lane, Manchester.

1872. Jack, Alexander, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1870. Jackson, John P., Mining Engineer, Clay Cross Coal and Iron Works, near Chesterfield.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.

1860. Jackson, Samuel, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1873. Jackson, Samuel, Assistant Locomotive Superintendent, Great Indian Peninsula Railway, Byculla, Bombay: (or care of W. Albert Jackson, 1 Mulberry Street, Sheffield.)

1872. Jackson, William Francis, Hallside Steel Works, Newton, near Glasgow.

1873. Jacob, Edward Westley, Windsor Iron Works, Garston, near Liverpool.

1866. Jaeger, Herrmann Frederic, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.

1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.

1870. Jamieson, John Lennox Kincaid, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan, Glasgow.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford.

1875. Jenkin, H. C. Fleeming, F.R.S., Professor of Engineering, University of Edinburgh; 3 Great Stuart Street, Edinburgh.

1861. Jessop, Thomas, Messrs. William Jessop and Sons, Park and Brightside Steel Works, Sheffield.

1854. Jobson, John, Derwent Foundry, Derby.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.

1872. Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

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1873. Jones, Edward, Drayton House, Trinity Road, Birchfield, Birmingham.

1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.

1867. Jones, George Edward, care of Messrs. James Nicol Fleming and Co., Calcutta: (or care of Edward Jones, Wylde Green, near Birmingham).

1869. Jones, John, Iron Trade Offices, Royal Exchange, Middlesbrough.

1872. Jones, William Richard Sumption, Executive Engineer, Workshops Division, Lower Ganges Canal, Narora, viâ Aligarh, India.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1869. Keep, Alfred, Metal Sheathing Works, 10 Coleshill Street, Birmingham.

1867. Kellett, John, 27 King Street, Wigan.

1873. Kelson, Frederick Colthurst, Superintending Engineer, City of Cork Steam Packet Co., Cork.

1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.

1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Kershaw, John, 9 Great Queen Street, Westminster, S.W.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1870. Kinsey, Henry, Postern Buildings, Swansea.

1872. Kirk, Alexander Carnegie, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan, Glasgow.

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.

1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.

1848. Kitson, James, Airedale Foundry, Leeds.

1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.

1874. Klein, Thorvald, Works Manager, Messrs. Brown Marshalls and Co., Britannia Railway Carriage and Wagon Works, Birmingham.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

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1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.
1863. Lancaster, John, Bilton Grange, Rugby.
1870. Lancaster, Joshua, Darwen Iron Works, Darwen; and 4 Leaf Square, Pendleton, Manchester.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1874. Laws, William George, Central Buildings, 18 Grainger Street West, Newcastle-on-Tyne.
1870. Layborn, Daniel, Messrs. Gladstone and Wyllie's Cotton Rice and Oil Factories, Rangoon, Burmah, India: (or care of Daniel Layborn, Sen., Beverley.)
1856. Laybourne, Richard, Rhymney Iron Works, Rhymney, Monmouthshire.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1865. Ledger, Joseph, Keswick.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton.
1874. Lees, James, Long Island Iron Works, Carlisle.
1863. Lees, Samuel, Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Town Hall Buildings, Manchester.
1866. Leigh, Joseph D., Ellesmere Foundry, Patricroft, near Manchester.
1870. Leonard, Edward James, East India Chambers, 23 Leadenhall Street, London, E.C.
1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn Quay, Gateshead.
1872. Leslie, Bradford, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons' Tyne Hæmatite Iron Works, Scotswood-on-Tyne.
1872. Lewis, Rowland Watkin, Britannia Boiler Tube Works, Ettingshall, Wolverhampton.
1860. Lewis, Thomas William, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.
1856. Linn, Alexander Grainger, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Linsley, Samuel W., Engineer, Whitburn Colliery, near Sunderland.
1866. Little, George, Messrs. Platt Brothers and Co.'s, Hartford Iron Works, Oldham.
1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1873. Llewellyn, William Hely, Messrs. Llewellyn and Cubitt, Rhondda Engine Works, Pentre, Rhondda Valley, Pontypridd.
1867. Lloyd, Charles, Glebe Buildings, Stoke-upon-Trent.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1871. Lloyd, Francis Henry, Old Park Iron Works, Wednesbury.

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1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1864. Lloyd, Sampson Zachary, Darlaston Steel and Iron Works, Wednesbury; and Areley Hall, Stourport.
1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.
1862. Lloyd, Wilson, Myvod House, Wood Green, Wednesbury.
1863. Loam, Matthew Hill, Gas and Water Engineer, Colwich Road, Nottingham.
1869. Lockhart, Humphrey Campbell, Messrs. Pilkington Brothers' Plate Glass Works, St. Helen's.
1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.
1856. Longridge, Robert Bewick, Chief Engineer, Steam Boiler Insurance Company, 67 King Street, Manchester.
1875. Longridge, Robert Charles, Assistant Manager, Steam Boiler Insurance Company, 67 King Street, Manchester.
1865. Longridge, William Smith, Boyne Grove, Maidenhead.
1866. Lord, Edward, Canal Street Works, Todmorden.
1861. Low, George, Bishop's Hill Cottage, Ipswich.
1873. Lowe, John Edgar, Engineer to Messrs. William Bird and Co., 2 Laurence Pountney Hill, London, E.C.
1873. Lucas, Arthur, 23 Delahay Street, Westminster, S.W.
1872. Lukin, Augustus Stephen, Newbold Road, Chesterfield.
1854. Lynde, James Gascoigne, Town Hall, Manchester.
1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

1864. Macfarlane, Walter, Saracen Foundry, Washington Street, Glasgow.
1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka; and Oriental Bank Corporation, Kobe, Japan: (or care of Dr. Maclagan, 136 Nethergate, Dundee.)
1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama, Japan.
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.
1873. Mair, John George, Manager, Messrs. Simpson and Co.'s Engine Works, Grosvenor Road, Pimlico, London, S.W.
1862. Mansell, Richard Christopher, Carriage Superintendent, South Eastern Railway, Ashford.
1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.
1862. Mappin, Frederick Thorpe, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

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1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred, Perseverance Iron Works, Heneage Street, Whitechapel, London, E. (*Life Member.*)

1865. Marshall, Francis Carr, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1862. Marshall, James, Hill Street, Rhymney, Monmouthshire.

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1859. Marshall, William Ebenezer, 1 Beech Grove Terrace, Leeds.

1847. Marshall, William Prime, 81 Newhall Street, Birmingham.

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge.

1853. Marten, Henry John, Parkfield Iron Works, near Wolverhampton.

1867. Martin, William, 13 Avenue de la Reine Hortense, Paris.

1857. Martindale, Lt.-Colonel Ben Hay, C.B., R.E., General Manager, London and St. Katharine Docks, Dock House, 109 Leadenhall Street, London, E.C.

1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.

1875. Matthews, James, Manager, Locomotive Boiler Works, Bridgwater Iron Works, Bridgwater.

1875. Matthews, Thomas William, Messrs. Leather Matthews and Co., Broughton Road Iron Works, Salford, Manchester.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1853. Maudslay, Henry, care of John Barnard, 8 Lancaster Place, Strand, London, W.C. (*Life Member.*)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 37 Bedford Street, Strand, London, W.C.

1869. May, George, Mining Engineer, Harton Collieries, Tyne Docks, South Shields.

1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.

1857. May, Walter, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.

1865. Maylor, John, Churton Lodge, Churton, near Chester.

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1859. Maylor, William, Messrs. Stanes Maylor and Co., Phœnix Coffee Works, Beypoor, Malabar Coast, India: (or care of Messrs. Stanes Watson and Co., 4 Cullum Street, Fenchurch Street, London, E.C.)

1874. McClean, Frank, 23 Great George Street, Westminster, S.W.

1872. McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.

1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.

1867. McEwen, James, Messrs. Firmstone and McEwen, Lays Iron Foundry, near Stourbridge.

1864. McEwen, Lawrence Thompson, Lombard House, George Yard, Lombard Street, London, E.C.

1868. McKay, Benjamin, Steel Company of Canada, Londonderry, Nova Scotia.

1872. McNeile, Alexander, Messrs. McNeile Brothers, Wheel and Axle Works, 26 John Street, Pentonville Road, London, N.

1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.

1858. Meik, Thomas, Messrs. Meik and Nisbet, 6 York Place, Edinburgh.

1857. Menelaus, William, Dowlais Iron Works, Dowlais.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire Engine Works, 63 Long Acre, London, W.C.

1867. Merryweather, Richard M., Messrs. Merryweather and Sons, Fire Engine Works, 63 Long Acre, London, W.C.

1862. Miers, Francis C., Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.; and Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newcastle-on-Tyne.

1870. Moberley, Charles Henry, Messrs. Eastons and Anderson's, Erith Iron Works, Erith, London, S.E.

1873. Möller, Peter T., Mining Engineer, Admiralty, St. Petersburg.

1872. Moon, Richard, Jun., Mersey Steel and Iron Works, Caryl Street, Liverpool.

1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.

1872. Moorsom, Warren Maude, London and North Western Railway, Locomotive Department, Crewe.

1864. Morgan, Joshua Llewelyn, Llanelly Iron and Tinplate Works, near Abergavenny.

1867. Morgans, Thomas, Newarne, Lydney.

1874. Morris, Edmund Legh, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.

1868. Morris, William, Waldridge Colliery, Chester-le-Street.

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1873. Morrison, Henry Martin, 15 Birch Lane, Longsight, Manchester.
1865. Mosse, James Robert, Public Works Office, Colombo, Ceylon.
1858. Mountain, Charles George, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.
1873. Muir, Edwin, Engineer, Rochdale Canal Navigation, Rochdale.
1863. Muir, William, 59 Shardeloes Road, New Cross, London, S.E.
1872. Mulliner, Charles, 29 Blackfriars, Manchester.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Sons, Vine Street, York Road, Lambeth, London, S.E.
1848. Napier, John, Messrs. Robert Napier and Sons, Engineers and Shipbuilders, Lancefield House, Glasgow.
1856. Napier, Robert, West Shandon, Helensburgh. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.
1869. Nelson, James, King's House Engine Works and Foundry, Sunderland.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1866. Newdigate, Albert Lewis, 2 The Pavement, Clapham Common, London, S.W. (*Life Member.*)
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, Wilton Cottage, Kenyon, near Manchester.
1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.
1869. North, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.
1870. Nye, Henry, Messrs. Varrall Elwell and Middleton's Works, 1 Avenue Trudaine, Paris.

1868. O'Connor, Charles, Messrs. John Elder and Co.'s, Fairfield Engine Works, Govan, Glasgow.
1875. Okes, John Charles Raymond, Manager, Messrs. Hayward Tyler and Co.'s Steam Pump Works, 84 Upper Whitecross Street, London, E.C.
1866. Oliver, William, Victoria and Broad Oaks Foundries, Chesterfield.

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1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.

1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.

1870. Osman, Joseph, Bey, Chief Engineer and Superintendent of Factories to the Khedive of Egypt, Boulac, Cairo; and St. James's Hotel, 77 Piccadilly, London, W.

1867. Oughterson, George Blake, Messrs. Manlove Alliott and Co., 45 Rue d'Elbeuf, Rouen, France.

1847. Owen, William, Wheathill Foundry, Rotherham; and Clifton House, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.

1869. Palmer, Alfred Septimus, Mining Engineer, Quayside, Newcastle-on-Tyne.

1871. Parke, Frederick, Withnell Fire Clay Works and Cotton Mill, near Chorley.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1871. Parkes, Pershouse, Tipton Chain Works, Castle Street, Tipton.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1874. Peaker, George, Engineer to the Small Arms Ammunition Factory, Kirkee, India.

1873. Pearce, Richard, Deputy Carriage Superintendent, East Indian Railway, Howrah, Bengal, India.

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India.

1848. Pearson, John, 15 Old Hall Street, Liverpool; and Golborne Park, near Newton-le-Willows, Lancashire.

1869. Pearson, William Hall, 50 Ann Street, Birmingham.

1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.

1866. Peele, Arthur John, Oakley House, Bellevue, Shrewsbury.

1848. Penn, John, F.R.S., The Cedars, Lee, London, S.E. (*Life Member.*)

1873. Penn, John, Jun., Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

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1874. Percy, Cornelius McLeod, Wigan Coal and Iron Co.'s Works, Kirkless Hall, Wigan.

1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.

1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton; and Slade Hill, Wolverhampton.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.

1867. Pidgeon, Daniel, Holmwood, Putney Hill, London, S.W.

1875. Platt, Edward, Messrs. Ackroyd and Platt, Albert Iron Works, Sowerby Bridge.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1869. Player, John, Clydach Foundry, near Swansea.

1866. Plum, Thomas Edward Day, 4 Headingley Terrace, Leeds.

1861. Plum, Thomas William, Old Park Iron Works, near Shiffnal.

1872. Pole, William, F.R.S., 31 Parliament Street, Westminster, S.W.

1860. Ponsonby, Edward Vincent, 1 Torquay Villa, Maindee, Newport, Monmouthshire.

1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. Potts, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.

1851. Potts, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.

1870. Powell, Thomas, (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas, (Nephew), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1867. Powell, William, Harbour Works, Douglas, Isle of Man.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1856. Preston, Francis, Turnbridge Iron Works and Forge, Huddersfield.

1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 37 West Sunniside, Sunderland.

1875. Prior, Johannes Andreas, Messrs. Burmeister and Wain's Engineering and Shipbuilding Works, Copenhagen.

1874. Prosser, William Henry, Messrs. Harfield and Co.'s, Mansion House Buildings, Queen Victoria Street, London, E.C.

1875. Provis, George Stanton, District Locomotive Superintendent, East Indian Railway, Assensole, India: (or care of T. J. Provis, The Grange, Ellesmere, near Shrewsbury.)

1866. Putnam, William, Darlington Forge, Darlington.

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1873. Radcliffe, Arthur Henry Wright, 7 Union Street, Birmingham.

1870. Radcliffe, William, Messrs. Hampton Radcliffe and Co., Phœnix Bessemer Steel Works, The Ickles, near Sheffield.

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1875. Rainford, Arthur, Manager, Messrs. Jessop and Co., Phœnix Foundry, Calcutta.

1864. Ramage, Robert, The Hollies, Sea Bank Road, North Egremont, near Birkenhead.

1847. Ramsbottom, John, Harewood Lodge, Mottram, near Manchester.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.

1860. Ransome, Allen, Jun., 304 King's Road, Chelsea, London, S.W.

1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.

1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Ratcliff, Daniel Rowlinson, Messrs. Thomas Milner and Son, Phœnix Safe Works, Smithdown Lane, Edge Hill, Liverpool.

1867. Ratliffe, George, Mersey Steel and Iron Co.'s Works, Caryl Street, Liverpool.

1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.

1872. Rawlins, John, Manager, Metropolitan Carriage and Wagon Co., Saltley Works, Birmingham.

1870. Reed, Edward James, C.B., M.P., Broadway Chambers, Westminster, S.W.

1859. Rennie, George Banks, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1875. Rich, William Edmund, Engineer, Messrs. Eastons and Anderson, 65 Southwark Street, London, S.E.

1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1863. Richardson, The Hon. Edward, Minister of Public Works, Wellington, New Zealand.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Engineer to Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

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1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland.

1863. Rigby, Samuel, Messrs. Armitage and Rigbys, Cock Hedge Mill, Warrington.

1871. Rigg, John, Deputy Locomotive Superintendent, London and North Western Railway, Crewe.

1874. Riley, James, Manager, Landore Siemens-Steel Works, Landore, Swansea.

1873. Robertson, George, Messrs. Vickarys and Robertson, West of England Engineering Works, Exeter.

1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury; and 13 Lancaster Gate, London, W.

1873. Robey, Robert, Jun., Trent Mining Co., Thrumpton, Keyworth, near Nottingham.

1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.

1865. Robinson, John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.

1872. Rofe, Henry, Resident Engineer, Corporation Water Works, Rochdale.

1868. Rogers, William, Imperial Railway Department, Yokohama, Japan; and Abercarn Fach, near Newport, Monmouthshire.

1871. Rollo, David, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1853. Ronayne, Joseph Philip, M.P., Rinn Ronain, Queenstown, Ireland.

1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.

1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.

1869. Rose, William Napoleon, Albert Iron Works, Moxley, near Wednesbury.

1874. Ross, John Alexander George, 34 Collingwood Street, Newcastle-on-Tyne.

1866. Rosthorn, Joseph De, Messrs. Rosthorn Brothers, Vienna.

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1857. Routledge, William, 4 Parsonage Buildings, Blackfriars, Manchester.

1860. Rumble, Thomas William, 15 St. Swithin's Lane, London, E.C. (*Life Member.*)

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

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1866. Sacré, Alfred Louis, 26 Parliament Street, Westminster, S.W.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.

1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1872. Salmon, Frank Barton, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.

1859. Salt, George, Sir Titus Salt Bart., Sons and Co., Saltaire, near Bradford.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.

1871. Sanders, Richard David, Manager, Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1861. Sanderson, George Grant, Redbourn Hill Iron and Coal Works, Frodingham, near Brigg.

1864. Sanderson, John, Weardale and Shildon District Water Works, Tunstall Reservoir, Wolsingham, near Darlington.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W.

1875. Saxon, George, Spring Works, Openshaw, Manchester.

1869. Scarlett, James, 14 St. Ann's Square, Manchester.

1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.

1875. Scott, Frederick Whitaker, Messrs. Scott Brothers' Wire and Hemp Rope Works, West Gorton, Manchester.

1868. Scott, George Lamb, 18 Nelson Street, Brook Street, Manchester.

1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of James H. Murray, 14 Marquis Road, Finsbury Park, London, N.)

1868. Scriven, Charles, Messrs. Scriven and Holdsworth, Leeds Old Foundry, Marsh Lane, Leeds.

1864. Seddon, John, 98 Wallgate, Wigan.

1873. Seddon, John Frederick, Mining Engineer, Great Harwood Collieries, near Accrington.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1867. Selby, Millin, Messrs. A. Karetnikoff and Son, Teakova Cotton Mill, near Ivanova, Vladimir, Russia: (or care of Atherton T. Selby, Atherton Old Hall, Leigh, near Manchester.)

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

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1872. Shanks, Arthur, Messrs. A. Burn and Co., Engineers and Contractors, 7 Hastings Street, Calcutta; and 11 Beaufort Gardens, Lewisham, London, S.E.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Co.'s Works, Birmingham.

1867. Sharpe, Charles James, Stowe House, London Road, Twickenham.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool; and 110 Cannon Street, London, E.C.

1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1872. Shirley, Henry Lionel, Engineer, Constantinovskoi Railway, South Russia; and 9 Queen's Gate Terrace, London, S.W.

1872. Shoolbred, James Nelson, 12 Delahay Street, Westminster, S.W.

1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1851. Siemens, Charles William, D.C.L., F.R.S., 12 Queen Anne's Gate, Westminster, S.W.; and 3 Palace Houses, Kensington Gardens, Bayswater Road, London, W.

1871. Simon, Henry, 7 St. Peter's Square, Manchester.

1847. Sinclair, Robert, Goodrington House, Paignton, South Devon.

1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, Clifton Park, Clifton, Bristol.

1866. Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.

1873. Smith, Charles, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.

1866. Smith, Edward Fisher, The Priory Offices, Dudley.

1866. Smith, George Fereday, Grovehurst, Tunbridge Wells.

1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness.

1859. Smith, Matthew, Caledonia Wire Mills, Halifax.

1857. Smith, William, 18 Salisbury Street, Strand, London, W.C.

1866. Smith, William, Messrs. A. and W. Smith and Co., Eglinton Engine Works, Glasgow.

1868. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

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1859. Sokoloff, General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)

1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Henry Tottie, 5 Great Winchester Street Buildings, London, E.C.)

1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.

1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.

1853. Spencer, Thomas, Nantyglo and Blaina Iron Works, Blaina, Monmouthshire.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.

1862. Stableford, William, Railway Carriage Works, Oldbury, near Birmingham.

1869. Stabler, James, Messrs. Shand Mason and Co., Fire Engine Works, 75 Upper Ground Street, Blackfriars Road, London, S.E.

1875. Stanger, William Harry, 23 Queen Anne's Gate, Westminster, S.W.

1874. Steel, Thomas Dyne, Bank Chambers, Newport, Monmouthshire.

1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 24 Great George Street, Westminster, S.W.

1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshire.

1866. Stevenson, John, Acklam Iron Works, Middlesbrough.

1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and 92 Lancaster Gate, Hyde Park Gardens, London, W.

1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1875. Stoker, Frederick William, Manager, Messrs. Shaw Johnson and Reay, The Moor Iron Works, Stockton-on-Tees.

1864. Stokes, James Folliott, Longview, Simla, India.

1873. Stonehouse, Marshall, care of Thomas Dale, Corporation Water Works, Hull.

1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.

1862. Strong, Joseph F., Rossetta Villa, Avenue Road, Southampton.

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

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1873. Strype, William George, Manager, Custom-House Flour Mill, Store Street, Dublin ; and 2 Sydenham Road, Dundrum, near Dublin.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Manager of Engineering Department, Bowling Iron Works, near Bradford.

1860. Swindell, James Evers, Parkhead Iron Works, Dudley ; and Oldswinford, near Stourbridge.

1864. Swindell, James Swindell Evers, Summerhill, Kingswinford, near Dudley.

1872. Symington, William Weldon, Bowden Steam Mills, Market Harborough.

1875. Tangye, George, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham.

1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham ; and Aviary Cottage, Illogan, near Redruth.

1859. Tannett, Thomas, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1873. Taylor, Charles Dyke, Mining Engineer, Cape Copper Mines ; care of J. C. Leaver, 6 Queen Street Place, London, E.C.

1861. Taylor, George, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Co., Derwent Foundry, 99 Constitution Hill, Birmingham.

1874. Taylor, Percyvale, Manager, Panther Lead Smelting Works, St. Philip's, Bristol.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1872. Teague, William, Mining Engineer, Tincroft Mines, Redruth.

1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.

1864. Thomas, Thomas, 34 West Bute Street, Cardiff ; and Bronygarn Villa, Roath, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1857. Thompson, Robert, Haigh Foundry, near Wigan.

1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.

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1875. Thoms, George Eastlake, Assistant Engineer, Municipal Offices, Dale Street, Liverpool.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1861. Thwaites, Robinson, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford.

1875. Thwaites, William Henry, Messrs. Thwaites and Carbutt's, Vulcan Iron Works, Thornton Road, Bradford.

1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.

1873. Tomkins, Edward, Montpelier Place, Fairfield, Buxton.

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co.'s, Atlas Works, Manchester.

1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Chapel Street Works, Edgware Road, London, N.W.

1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.

1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.

1865. Trow, John James, Messrs. William Trow and Sons, Union Foundry, Wednesbury.

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Holyhead Road, Wednesbury.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.

1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.

1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W.

1874. Twibill, Joseph, Engineer and Ironfounder, Barrack Street, Tatton Street, Chester Road, Manchester.

1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1875. Unsworth, Thomas, Leicester Works, Dutton Street, Strangeways, Manchester.

1862. Upward, Alfred, 11 Great Queen Street, Westminster, S.W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of John Maclachlan, 15 Hamilton Street, Greenock.)

1872. Usher, Thomas, Messrs. Reay and Usher, South Hylton Iron Works, Sunderland.

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1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1875. Wailes, John William, Landore Siemens-Steel Works, Landore, Swansea.
1865. Wainwright, William, West Central Wagon Works, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1873. Waldenström, Eric Hugo, Manager, Broughton Copper Co.'s Works, Broughton Road, Manchester.
1872. Walker, Alexander, Locomotive Superintendent, Cambrian Railways, Oswestry.
1870. Walker, Alfred, Albion Iron Works, Aldwark, York.
1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.
1864. Walker, Bernard Peard, Eagle Foundry, Broad Street, Birmingham.
1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire; and Lilleshall Old Hall, near Newport, Shropshire.
1875. Walker, George, 95 Leadenhall Street, London, E.C.
1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan.
1875. Walker, William, Mining Engineer, Saltburn-by-the-Sea.
1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.
1865. Waller, George Arthur, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.
1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.
1865. Walpole, Thomas, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.
1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.
1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.
1874. Warner, Edward, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.

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1874. Wass, John William, Messrs. Wright Wass and Co., 27 Quayside, Newcastle-on-Tyne.

1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.

1862. Watkins, Richard, Messrs. Jackson and Watkins, Canal Iron Works, Poplar, London, E.

1866. Watson, Robert, Engineer, Ferryhill Colliery, Ferryhill.

1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.

1875. Webster, John, Messrs. Hopkins and Webster, Fundicão da Jequitaia, Bahia: (or care of Thomas C. Fawcett, Clarendon Foundry, Water Lane, Leeds.)

1872. Welch, Edward John Cowling, Stephenson Boiler and Forge Co., Failsworth, Manchester.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1871. West, Henry Joseph, Messrs. Siebe West and Co., Mason Street, Westminster Bridge Road, Lambeth, London, S.E.

1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.

1862. Westmacott, Percy Graham Buchanan, Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne.

1867. Weston, Thomas Aldridge, 10 South Delaware Avenue, Philadelphia, Pennsylvania, United States: (or care of William T. Watts, 81 Parade, Birmingham.)

1874. Whalley, Arthur John, Prince's Street, Truro.

1867. Wheatley, Thomas, Manager, Wigtownshire Railway, Wigtown, Wigtownshire.

1856. Wheeldon, Frederick B., Highfields Engine Works, Bilston; and 16 Waterloo Road, Wolverhampton.

1872. Whieldon, William, Messrs. Whieldon and Cooke, Collinge Engineering Works, 190 Westminster Bridge Road, Lambeth, London, S.E.

1874. White, Henry Watkins, Newton Villa, Ashfirdd, Ross.

1864. White, Isaias, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1868. Whitehead, Peter Ormerod, Ilex Cotton Mill, Rawtenstall, near Manchester.

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1873. Whitley, John Robinson, Railway Works, Hunslet Road, Leeds; and Albert Buildings, Queen Victoria Street, London, E.C.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.

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1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and The Firs, Fallowfield, Manchester.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford.

1868. Wigram, Reginald, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.

1867. Wilkes, Gilbert, Bordesley Tube Mills, Liverpool Street, Birmingham.

1867. Wilkes, John, Bordesley Tube Mills, Liverpool Street, Birmingham.

1868. Wilkieson, Colonel Charles Vaughan, R.E., care of Messrs. Richardson and Co., 23 Cornhill, London, E.C.

1874. Williams, David, Manager, Pontypool Iron and Tinplate Works, Pontypool.

1865. Williams, Edward, Cleveland Lodge, Middlesbrough.

1872. Williams, Sir Frederick Martin, Bart., M.P., Perran Foundry, Goonvrea, Perranarworthal, Cornwall.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, 9 Great George Street, Westminster, S.W.

1869. Williams, Walter, Wednesbury Oak Iron Works, Tipton.

1873. Williams, William Lawrence, Manager, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1870. Willman, Charles, 1 Cleveland Terrace, Middlesbrough.

1872. Wilson, Alfred, Messrs. Howson and Wilson, 2 Exchange Place, Middlesbrough.

1856. Wilson, Edward, 9 Dean's Yard, Westminster, S.W.

1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1863. Wilson, John Charles, Avonside Engine Works, St. Philip's, Bristol.

1857. Wilson, Robert, F.R.S.E., Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.

1872. Wilson, Stephen, Engineer, Wearmouth Colliery, Sunderland.

1873. Wilson, Thomas Sipling, Messrs. Wilson and Jessop, 71 Cornhill, London, E.C.

1867. Winby, Frederick Charles, Lanelay Hall, near Cardiff.

1872 Winn, Charles William, 30 Easy Row, Birmingham.

1872. Winstanley, Robert, Jun., Mining Engineer, Lancaster Avenue, Fennel Street, Manchester.

1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.

1872. Wise, William Lloyd, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.

1872. Withinshaw, John, Birmingham Engine Works, Wiggin Street, Icknield Port Road, Birmingham.

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1871. Withy, Edward, Messrs. Withy and Co., Middleton Iron Shipbuilding Yard, Hartlepool.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1873. Woodhead, John Proctor, 16 Tib Lane, Manchester.

1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.

1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.

1874. Worsdell, Thomas William, London and North Western Railway, Locomotive Department, Crewe.

1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Manchester.

1866. Wren, Henry, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.

1867. Wright, John Roper, Hallside Steel Works, Newton, near Glasgow.

1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.

1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton.

1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.

1871. Wright, William, Lostwithiel.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1873. Young, Charles Frederic Trelawny, 112 St. Donatt's Road, New Cross, London, S.E.

1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.

1861. Yule, William, 102 New Canal, St. Petersburg.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin; and 4 The Hill, Monkstown, near Dublin.

1867. Morin, General Arthur, Director, Conservatoire National des Arts et Métiers, Paris.

1867. Tresca, Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

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ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1873. Barry, William Henry, 7 Birchin Lane, London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.
1873. Freeman, William George, Messrs. John Freeman and Sons, Granite Works, Penryn, Cornwall.
1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1875. Greenwood, John, Portland Mills, Bradford.
1865. Hall, John, 56 King Street, Manchester.
1874. Hardcastle, Robert Anthony, Clarence Iron Works, Leeds.
1874. Hurman, James, Traffic Superintendent, Taff Vale Railway, Cardiff; and 22 Albert Terrace, Charles Street, Cardiff.
1875. Knight, John Henry, Weybourne House, Farnham.
1858. Lawton, Benjamin C., Corbridge, Northumberland.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 2 Crown Buildings, Queen Victoria Street, London, E.C.
1860. Manby, Cordy, Messrs. Moore and Manby, Castle Street, Dudley.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield.
1874. Paget, Berkeley, Low Moor Iron Office, 98 Cannon Street, London, E.C.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1871. Patterson, John, Liverpool and Manchester District Bank, Spring Gardens, Manchester; and Craigdarragh, Belfast.
1874. Pepper, Joseph Ellershaw, Monkbridge Iron Works, Leeds.
1856. Pettifor, Joseph, Midland Railway, Derby.
1875. Schofield, Christopher J., Clayton, near Manchester.
1859. Sherriff, Alexander Clunes, M.P., 10 Dean's Yard, Westminster, S.W.; and Craycombe House, near Pershore.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1869. Varley, John, Farnley Iron Works, Leeds.
1865. Warden, Thomas, Lionel Street, Birmingham.
1875. Wasalekar, Nanaji Narayan, care of Dr. Atmaram Pandurang, Candewadi, Bombay; and 1 Platt View, Rusholme, Manchester.
1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Associate.*)

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GRADUATES.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1872. Armstrong, Thomas, Carriage Department, Great Western Railway, Shrewsbury.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1869. Blake, Frederick William, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1874. Browne, Tomyns Reginald, Locomotive Works, Midland Railway, Derby.

1873. Collingham, Robert Moss, Messrs. Good Collingham and Menzies, Green Lane Foundry, Hull.

1875. Dawson, Edward, Haswell Colliery, Fence Houses.

1873. Dobson, Richard Joseph Caistor, Sugar Fabric Trankil, Pattie, Japara, Java: (or care of Richard Dobson, Dolforwyn Hall, Abermule, Montgomeryshire.)

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street, Summer Lane, Birmingham.

1873. Edmunds, John Sharp Wilbraham, Elmsdale, Carpenter Road, Edgbaston, Birmingham.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.

1875. Ffolkes, Martin William Brown, Superintending Engineer, Sewerage Works, Town Hall, Wisbeach.

1867. Flavel, Sidney, Jun., Eagle Foundry, Leamington.

1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.

1874. Hedley, Henry, Trinity Terrace, London Road, Derby.

1874. Hedley, Thomas, Locomotive Works, Midland Railway, Derby.

1867. Holland, George, care of John Holland, Navigation Old Yard, Castle, Northwich.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons' Sheaf Works, Sheffield.

1867. Mayhew, Horace, Mining Engineer, Hindley House, near Wigan.

1867. Mitchell, John, Swaithe Colliery, Barnsley.

1868. Moor, William, Jun., Lanelay Colliery, Llantrissant, Glamorganshire.

1872. Napier, Robert Twentyman, Messrs. John Penn and Sons' Marine Engine Works, Greenwich, S.E.

1867. Pearson, John Edward, Golborne Park, near Newton-le-Willows, Lancashire.

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1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1874. Rankeilor, William Collis, Wednesbury Oak Iron Works, Tipton.

1873. Ratcliff, John Francis, Phœnix Safe Works, Smithdown Lane, Edge Hill, Liverpool.

1875. Sheppard, Herbert Gurney, Messrs. James Watt and Co.'s Works, Soho Foundry, near Birmingham.

1873. Simpson, Alfred, Messrs. Fowler and McCollin's, Vulcan Iron Works, Scott Street, Hull.

1870. Smith, Michael Holroyd, Caledonia Wire Mills, Halifax.

1874. Stephenson, Joseph, Chatterley Iron Works, Tunstall, near Stoke-upon-Trent.

1874. Taylor, Arthur, 6 Queen Street Place, Upper Thames Street, London, E.C.

1871. Thurgood, Ernest Charles, Messrs. Greenwood and Batley's, Albion Works, Armley Road, Leeds.

1875. Walker, Arthur Henry, The Grove, Tettenhall, Wolverhampton.

1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.

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PROCEEDINGS.

January, 1875.

The Twenty-eighth Anniversary Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 28th January, 1875; Frederick J. Bramwell, Esq., F.R.S., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1875.

The Council now beg to lay their Annual Report before the Meeting on this occasion of the Twenty-eighth Anniversary of the Institution.

The roll of the Institution shows that at the end of the last year 1874 there were

Members	Hon. Life Members	Associates	Graduates	Total
927	4	28	33	992

as compared with

Members	Hon. Life Members	Associates	Graduates	Total
895	4	29	28	956

at the corresponding period of the previous year, showing an effective increase of 36. This increase arises as follows.

There have been elected within the year

Members	Associates	Graduates	Total
68	4	7	79

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there have been lost by death

Members	Associates	Graduates	Total
17	0	0	17

and by resignations or by removal from the register

Members	Associates	Graduates	Total
23	3	0	26

so that while the gain from elections has amounted to 79, there must be deducted from this the loss of 43 arising from the causes above stated, leaving the net increase of 36 before mentioned. The Council look upon this condition of things as very satisfactory so far as it goes, and as showing that the merits of the Institution are largely recognised by that class from whom its members should be drawn.

With respect to the Financial position, the appended Balance Sheet will show that, including a balance of £9317 1*s*. 0*d*. from the previous year, there has been a total credit of £12,587 14*s*. 2*d*.; that the expenses have been £2244 1*s*. 11*d*., leaving a balance of £10,343 12*s*. 3*d*. This balance it will be seen is £1026 11*s*. 3*d*. in excess of that with which the year 1874 was begun, and thus the expenses of the year 1874 have been £1026 11*s*. 3*d*. within the true income of that year, irrespective of any question of balance. The Council therefore feel that the Members may be well satisfied with the financial position of the Institution. The greater portion of the present balance is invested in £6000 London and North Western Railway 4 per cent. Debenture Stock, £1000 Midland Railway 4 per cent. Debenture Stock, £1000 Great Western Railway 4 per cent. Debenture Stock, and £1200 North Eastern Railway 4 per cent. Debenture Stock, registered in the names of Mr. John Ramsbottom, Mr. Frederick J. Bramwell, and the late Mr. Sampson Lloyd, as interim trustees on behalf of the Institution. The Finance Committee have examined and checked the receipts and payments of the Institution for the past year, and report that the following Abstract of Receipts and Expenditure rendered by the Treasurer is correct.

(*See Abstract appended.*)

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The following Deceases of Members of the Institution have occurred during the past year:—

ROBERT BROAD,	Tipton.
THOMAS SNOWDEN BUTLER,	Leeds.
THOMAS CARR,	Bristol.
FRANCIS NORTH CLERK,	Wolverhampton.
BENJAMIN DOBSON,	Southport.
JAMES EASTWOOD,	Derby.
SIR WILLIAM FAIRBAIRN, BART.,	Manchester.
SAMUEL CLOUGH FAVIELL,	Leeds.
JAMES FLETCHER, JUN.,	Manchester.
CHARLES FREDERICK GURDEN,	Liverpool.
JAMES INNES HOPKINS,	London.
JOHN HOSKING,	Gateshead.
WILLIAM BLAKE LAMBERT,	London.
SAMPSON LLOYD,	Wednesbury.
JOHN MANNING,	Leeds.
WILLIAM MARTLEY,	London.
SAMPSON MOORE,	Liverpool.
FREDERICK HENRY RICKETTS,	London.
THOMAS ROSE,	Wolverhampton.
JAMES SAMUEL,	London.
PETER WRIGHT,	Dudley.

Comprised in these were many valuable friends of the Institution, and prominent among them were Sir William Fairbairn, Bart., Past-President, and Mr. Sampson Lloyd, long a Vice-President of the Institution. At the October Meeting their deaths were officially announced, and resolutions were passed expressive of the deep regret felt for the loss of these two Members, and of sincere sympathy with their relatives.

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. They trust the Members generally will promote the formation of a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and Members are requested to present copies of their Works to the Library of the Institution.

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LIST OF DONATIONS TO THE LIBRARY.

On the Locomotives at the Vienna Exhibition 1873, by J. Morandière; from the author.

On an improved method for Overcoming Steep Gradients on Railways, by Henry Handyside; from the author.

Elementary Treatise on Steam, by J. Perry; from the publishers.

Lectures on Telegraphy; from the School of Military Engineering, Chatham.

A first book of Mining and Quarrying, by J. H. Collins; from the author.

Handbook to the Mineralogy of Cornwall, by J. H. Collins; from the author.

List of Chinese Lighthouses, Lightvessels, Buoys, &c., 1874; from Mr. D. M. Henderson.

Topographical Survey of the Adirondack Wilderness of New York; from Mr. Verplanck Colvin.

United States Geological Survey; from Dr. F. V. Hayden, United States Geologist.

Victorian Patent Indexes; from the Agent General for Victoria.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Journal of the French Society for the Encouragement of National Industry; from the Society.

Journal of the Hanover Architect and Engineer's Society; from the Society.

Journal of the Saxon Society of Engineers; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Transactions of the American Society of Civil Engineers; from the Society.

Report of the Bombay Mechanics' Institute; from the Institute.

Proceedings and Journal of the Asiatic Society of Bengal; from the Society.

Proceedings of the Institution of Civil Engineers; from the Institution.

Transactions of the North of England Institute of Mining Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Journal of the Iron and Steel Institute; from the Institute.

Transactions of the Society of Engineers; from the Society.

Transactions of the Society of Civil and Mechanical Engineers; from the Society.

Proceedings of the Cleveland Institution of Engineers; from the Institution.

Transactions of the Chesterfield and Derbyshire Institute of Engineers; from the Institute.

Proceedings of the Royal Society of London; from the Society.

Report of the British Association for the Advancement of Science; from the Association.

Smithsonian Institution Annual Report; from the Institution.

Transactions of the Institution of Naval Architects; from the Institution.

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Transactions of the Institution of Surveyors; from the Institution.
Journal of the Royal United Service Institution; from the Institution.
Proceedings of the Royal Artillery Institution; from the Institution.
Journal of the Royal Agricultural Society of England; from the Society.
Proceedings of the Royal Institution of Great Britain; from the Institution.
Transactions of the Royal Scottish Society of Arts; from the Society.
Proceedings of the Philosophical Society of Glasgow; from the Society.
Journal of the Liverpool Polytechnic Society; from the Society.
Journal of the Royal Cornwall Polytechnic Society; from the Society.
Journal of the Society of Arts; from the Society.
Reports of the Manchester Steam Users' Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.
Report of the Manchester Boiler Insurance Company; from Mr. Robert B. Longridge.
Report of the Midland Steam Boiler Association; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
The Engineer; from the Editor.
Engineering; from the Editor.
Iron; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.

In the course of 1874 the usual Meetings, the Anniversary Meeting, the Spring Meeting, the Summer Meeting, and the Autumn Meeting, were held. Two days were devoted at the Summer Meeting to the reading and discussion of Papers, making five days in all thus occupied in the course of the year. During these five days several valuable and important Papers were contributed, many of which led to useful practical discussions. The list of Papers is as follows:—

On Hydraulic Machinery for Steering, Reversing, and Discharging Cargo &c. in steamships; by Mr. Andrew Betts Brown.
On the Transmission of Water Power by Turbines and Wire Ropes; by Mr. Henry M. Morrison.
On Rock Drilling Machinery; by Mr. Thomas B. Jordan.
On the Bute Docks at Cardiff, and the Mechanical Appliances for Shipping Coal; by Mr. John McConnochie.
On the Pumping Machinery for emptying the Dry Docks at Chatham and at Rio de Janeiro; by Mr. George B. Rennie.
On the application of Water Pressure to driving Machinery and working Shop Tools; by Mr. Ralph H. Tweddell.

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On Compressed-Air Machinery for Underground Haulage; by Mr. William Daniel.

On Direct-acting Pumping Engines and Pumps for high lifts in Mines; by Mr. Henry Davey.

On the Helical Pump; by Mr. John Imray.

The Anniversary Meeting was held in Birmingham, on which occasion there were present 71 members and 25 friends. The Spring Meeting and the Autumn Meeting were held, through the courtesy of the Council of the Institution of Civil Engineers, at the house of their Institution in London. The attendances were, at the Spring Meeting 108 members and 63 friends and members of the Civil Engineers, and at the Autumn Meeting 88 members and 58 friends.

The Summer Meeting was held in Cardiff, and the Council think the Institution may be congratulated upon that meeting as having been a great success; the attendance was 149 members and 85 friends. The papers and discussions were probably among the very best that there have been during the year. But the principal feature of the Cardiff Meeting was the series of visits paid to Works in the neighbourhood, including the Bute and Penarth Docks, the Rhondda and Aberdare Valley Collieries, the Dowlais and Cyfarthfa Iron Works, the Landore Siemens-Steel Works, the Morfa Copper Works and Landore Tinplate Works, the Mwyndy Iron Ore Mine, the Merthyr Sewage Farm, the Diamond Rock-Drilling, and the Crumlin Viaduct. Every facility was afforded by the Railway Companies for obtaining access to Cardiff, and for making the various Excursions; and the Council desire to express the thanks of the Institution to the Railway Companies, and also to the Local Committee at Cardiff, and to the Proprietors of Works for the liberal spirit and the hospitality which threw open the works to free inspection and provided for the comfort of the Members when those inspections were made. The Council cannot refrain from bringing two names from among their own body prominently forward in respect of this Cardiff visit: the one is that of Mr. Menelaus, Vice-President, to whose position in the district they believe the Members are largely indebted for the cordiality

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of their reception; the other that of Mr. Siemens, Past-President, for the extremely interesting visit to Landore, and for his hospitality on that occasion.

Although the number of Members in an Institution may continue to increase, and its financial condition may be prosperous, it does not of necessity follow that the Institution is in a satisfactory state, still less that it is doing the very best that it could do. There is always a fear that the sort of stagnation and contentment arising from prosperity may set in, and may check, or enfeeble, efforts for advancement. The Council for the year 1873 entertaining these views deemed it expedient that steps should be taken for improving and extending the useful action of the Institution, and they called attention to the subject in the last Report. The Council for 1874 have devoted much time and great attention to the consideration of what should be the steps for giving effect to the recommendations of their predecessors.

One direction in which the useful action of the Institution could be extended would be an increase in the number of meetings, and the consequent increase in tho papers contributed. At first the Council hoped to be able to propose a considerable addition to the meetings, but they regret to say the difficulty of obtaining papers of sufficient merit, for the five days of meeting every year, is so great, that they feared to do more at present in this direction than to propose one other day in the year, making six in all. They believe, from the enquiries they have instituted, it will best suit the convenience of Members that the sixth day should be obtained by making the London Spring Meeting a meeting of two consecutive days. A member has a notice of motion on the paper for today "That the Council be empowered to appoint a Meeting in each year to be held in Manchester." Assuming that this proposal is agreed to, the arrangement for the Meetings would in future years be as follows:—

The Anniversary Meeting in January in Birmingham.
The Spring Meeting of two days in succession in London.
The Summer Meeting at some one town to be selected in each year.
The Autumn Meeting in Manchester.

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Reverting to the subject of the difficulty of obtaining Papers, the Council, with a view not only of adding to the number but of improving the quality of the papers, and of obtaining, as far as possible, not merely descriptive papers, but papers involving research, believe that it will be well to devote from the funds of the Institution £150 to be given in each year in two prizes of £100 and £50 for the two best papers contributed in that year; with a distinct understanding however, that if unhappily among all the papers read there should be none which in the opinion of the Council were of sufficient merit, the prize or prizes of that year should be withheld altogether. The Council propose that from £15 to £20 of these sums should be appropriated to the purchase of a handsome Gold Medal for each prizeman, and that the remainder should in every case be given in money. The Council are well aware of the great expense which may be, and almost inevitably is, attendant upon the preparation of a really valuable paper; and they desire to compensate in the cases of the most highly successful papers for this outlay, by awarding the principal part of the premium in money, while at the same time they propose to give a medal which shall be not only a token of honour, but shall also possess considerable intrinsic value. But the Council do not rely upon these premiums alone for obtaining the desired valuable papers. They trust that when the Members are appealed to, as the Council most earnestly appeal to them now, no difficulty will be found in obtaining from the 900 Members who now belong to the Institution as many highly meritorious papers as will suffice for the Meetings of the year.

The Council believe that a further mode of increasing the efficiency of the Institution will be to devote a portion of the funds to the investigation of questions connected with the science of Engineering; and they therefore propose that a sum not exceeding £200 per annum be available for the investigation of any matter falling within the above description, which may press for further research.

In order to render the Transactions more valuable for reference, the Council purpose that there should be published with each

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volume not merely a list of papers, but a subject-matter and personal index, comprising the contents of the papers and discussions. The volume for 1874 will appear with its own index, and the Council intend as speedily as possible to prepare a General Index on a similar plan for the whole of the other volumes from the commencement of the Institution. A Library Catalogue also will shortly be published.

In order to enable the Members more readily to follow the papers at the meetings, these will be printed, and the printed copies will be circulated in the meeting room; and any Member proposing to attend a meeting where a paper is to be read will on making application have a copy sent to him some days before the meeting.

The Council believe that the suggestions made in this Report, if adopted by the Meeting, will tend to the advancement of the Institution; but to make them really successful there must be a hearty co-operation of the Members; and in concluding this Report the Council desire most earnestly once more to appeal to every Member to give his best aid to the advancement of this Institution, which during the last quarter of a century has done good work in the development of mechanical science, and will, if we only devote ourselves to it with zeal, not only hold its own, but will advance so as to continue to be in the front rank of Engineering Societies.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the Rules of the Institution; and the ballot taken at the present meeting will show the election of the Officers and Council for the ensuing year.

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SUBJECTS FOR PAPERS.

STEAM ENGINE BOILERS, particulars of construction—form and extent of heating surface—extent of water surface—relation of grate surface to heating surface, and heating surface to fuel consumed—relative value of radiant surface and flue surface in effect and economy—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—combined air and steam—safety valves—water gauges—explosion of boilers, and means of prevention—strength and proportions of riveted joints, single and double riveting—welded joints—comparative strength of drilled and punched plates in iron and in steel—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—small water-space boilers for specially high pressures—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel; coal, wood, charcoal, peat, coke, and artificial fuel—mechanical firing, moveable grates and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed-water—mode of feeding—use of injector—circulation of water—self-acting feeding apparatus.

STEAM ENGINES—expansive force of steam, and best means of using it—effect of steam jackets—power obtained by various plans—comparison of double and single-cylinder engines—combined engines—compound-cylinder engines—comparative advantages of direct-acting and beam engines—horizontal and vertical engines—condensing and non-condensing engines—construction and particulars of working of injection and surface condensers—ejector condenser—air-pumps—piston speed—pistons, slide-valves, and other valves—governors—throttle valves—bearings, &c.—improved expansion gear—expansion gear controlled by governor—indicator diagrams from engines, comparison of these diagrams with dynamometer experiments, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

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PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—indicator diagrams from pumps—construction of pumps—plunger pumps—bucket pumps—rotary and centrifugal pumps—details of different pump valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

BLAST ENGINES, best kind of engine—details of construction—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from steam cylinder, blast cylinder, and blast main.

MARINE ENGINES, power of engines in proportion to tonnage—dimensions and form of vessel—different constructions of engines, compound-cylinder engines, trunk engines, oscillating engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—surface condensers—salinometers—weight of machinery, and boilers—speed obtained in different steamers, with particulars of construction of engines—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—economy of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood—construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast-pipe—construction of pistons, valves, expansion gear, &c.—balanced slide-valves—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—steam breaks, counterpressure steam break—distribution of weight on wheels.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural

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purposes—barn machinery—field implements—ploughing engines—traction engines, particulars of performance and cost of work done.

STEAM ROAD ROLLERS, particulars and results of working.

HOT-AIR ENGINES—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—accumulator—hydraulic machinery—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—stone-dressing machinery.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in opening, carding, spinning, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

WEAVING MACHINERY, for manufacture of different materials—improvements in looms, &c.

LACE MACHINERY, particulars of improvements.

KNITTING MACHINERY, worked by hand or by power—particulars of improvements.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form

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of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws—saw sharpeners.

WOOD-WORKING MACHINES, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

STONE-WORKING MACHINERY—cutting, planing, turning, and polishing machines.

GLASS MACHINERY—manufacture of plate and sheet glass—grinding and polishing machinery—construction of melting furnaces, annealing kilns, &c.

LATHES, PLANING, BORING, DRILLING, SLOTTING, AND SHAPING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolling mills.

HAMMERS, improvements in construction and application—steam hammers—friction hammers—air hammers—tilt hammers.

RIVETING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—rivet-making machines—comparative strength of hand and machine riveting—plate-bending and flanging machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

FIRE ENGINES, hand and steam, ditto ditto ditto.

SLUICES AND SLUICE COCKS, worked by hand or by hydraulic power, ditto.

CRANES—steam, hydraulic, and pneumatic cranes—travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses, blast-furnaces, &c.—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery—cutting teeth by machinery.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, adhesion, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

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DYNAMOMETERS, construction, application, and results of working.

PRESSURE GAUGES, for steam and water—varieties of construction—durability and results of working—speed indicators for vessels and trains.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work, drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of testing—influence of temperature on strength.

GIRDERS OF CAST AND WROUGHT IRON, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks—friction of ropes.

ROOFS, particulars of construction for different purposes—cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost—durability in various climates and situations—comparative cost, weight, and durability.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials—means of rendering timber &c. incombustible.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

GAS WORKS—best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas-meters—self-regulating meters—pressure

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of gas—gas exhausters, construction and results of working—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

WATER WORKS, facts relating to—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—incrustation in pipes, effect on delivery, and means of prevention or removal—strength and durability of pipes and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-acting valves—relief valves—machinery for working sluices—water meters, construction and working.

WELL SINKING AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFERDAMS AND PILING, facts relating to construction—cast-iron sheet piling.

PIERS, fixed and floating, and pontoons—particulars of construction.

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles—pile shoes.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

EXCAVATING MACHINES, construction and results of working.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

SUBAQUEOUS ENGINEERING, particulars of works.

LIGHTHOUSES, cast-iron and wrought-iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—iron and steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam and hydraulic power to steering—instruments to record rolling of ships and to ascertain stability.

GUNS, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—shot and shells, cast-iron and steel, manufacture and proof.

SMALL ARMS, machinery for manufacture of rifles and cartridges, &c.—breech-loading mechanism.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, dynamite, &c.—effects produced by large and small charges of powder—arrangement of charges.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—rock-drilling machines—means of

ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—hauling arrangements underground and at surface—stone-breaking machines—mode of breaking, pulverising, and dressing various descriptions of ores—coal-washing machinery.

BLAST FURNACES, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast stoves—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace, and mode of charging.

PUDDLING FURNACES, best forms and construction—gas furnaces—application of machinery to puddling.

SMELTING FURNACES, for reduction of copper, tin, and lead ores, &c.—best construction and modes of working.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CUPOLAS, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

BLOWING FANS, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.

VENTILATING FANS for mines—ventilating machines—mechanical ventilation and warming of public buildings.

FUEL, solid, powdered, liquid, gaseous.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal-slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

RAILWAYS, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

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SIGNALS for stations and trains, and self-acting signals—interlocking apparatus for signals and points—switch locks.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—construction—laying and picking-up machinery.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks—steam, air, and hydraulic breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—self-acting couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture—durability, and causes of fracture.

PREPARATION OF PAPERS.

The Papers to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left edge. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

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INSTITUTION OF MECHANICAL ENGINEERS.

Abstract of Receipts and Expenditure,

For the year ending 31*st December* 1874.

Cr.				£	s.	d.
By Balance 31st Dec. 1873; Invested	7978	16	2			
In Bank	1338	4	10	9317	1	0
„ Subscriptions from 44 Members in arrear				132	0	0
„ do. 3 Associates in arrear				9	0	0
„ do. 806 Members for 1874				2418	0	0
„ do. 23 Associates for 1874				69	0	0
„ do. 30 Graduates for 1874				60	0	0
„ do. 11 Members in advance				33	0	0
„ Entrance Fees from 67 New Members				134	0	0
„ do. 4 New Associates				8	0	0
„ do. 7 New Graduates				7	0	0
„ do. 1 Graduate transferred to Member				1	0	0
„ Sale of Extra Reports				33	6	0
„ Interest; From Bank	33	2	2			
On £8000 Stock at 4 p.c. one year, less inc. tax	316	6	8			
On £1200 Stock at 4 p.c. 130 days, less inc. tax	16	18	4	366	7	2
				£12,587	14	2

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	657	16	7			
Less Authors' copies of Papers, repaid	12	4	0	645	12	7
„ Stationery, Binding, Printing of Circulars, &c.				95	10	0
„ Office Expenses, Clerks, and Petty Disbursements				91	12	5
„ Coal, Gas, and Water				31	8	2
„ Expenses of Meetings				101	19	7
„ Fittings and Repairs				4	7	8
„ Travelling Expenses				69	16	9
„ Parcels				4	19	5
„ Postages				120	9	11
„ Salaries				956	19	9
„ Insurance				2	10	0
„ Rent and Taxes				118	15	8
Balance 31st Dec. 1874; Invested	9178	16	2			
In Bank	1014	16	1			
Cash in hand	150	0	0	10,343	12	3
				£12,587	14	2

(Signed) CHARLES COCHRANE,
EDWARD A. COWPER,
WALTER MAY, } Finance Committee.

28th January 1875.

MEMOIRS

OF MEMBERS DECEASED IN 1874.

Robert Broad was born in 1821, and was proprietor of the Horseley Iron Works, Tipton, for about twenty-seven years, continuing so to the time of his death, which took place on 2nd January 1874, at the age of 52, after a very short illness. He was a Member of the Institution from 1848.

Thomas Snowden Butler was born at Kirkstall, near Leeds, on 2nd July 1846, being the second son of Mr. John Octavius Butler of the Kirkstall Forge Co. After serving his apprenticeship in the shops and drawing offices at those works, he had the management of the engineering department there, during which time he had charge of carrying out the several large and important undertakings executed by the firm. His death occurred very suddenly from the rupture of a blood vessel on 17th September 1874, in the 29th year of his age. He became a Graduate of the Institution in 1866.

Thomas Carr, third son of the late Rev. John Carr, professor of mathematics in the University of Durham, was born at Durham on 23rd January 1824, and as a boy very early showed a decided turn for mechanics. At the age of fifteen he was placed with Messrs. Bury Curtis and Kennedy of Liverpool, where he remained three years, and distinguished himself by the correctness of his drawings. He invented an improved steering apparatus for ships, which was highly approved by competent authorities, but was not generally adopted owing to the expense required in fixing. Some time afterwards he brought out a new method of drying glue, which could be used at any time—a matter of great importance in the manufacture of this article; and it was disposed of to a manufacturer in Leeds. He also originated several other inventions, the last

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and principal one, by which he is best known, being the disintegrator. This machine, of which he gave a description to the Institution (see Proceedings Inst. M. E. 1872 p. 28) is now extensively used in various trades and manufactures and in connection with agriculture; it is allowed to be one of the most remarkable and valuable inventions of recent years. He also brought out a flour mill on the disintegrator principle, which is a good deal used in Scotland, and appreciated there. His death took place at Bristol on 29th March 1874, at the age of 50. He became a Member of the Institution in 1872.

Francis North Clerk was born in 1829, being the son of a naval officer and grandson of the celebrated Scotch judge, John Clerk, afterwards Lord Eldin. He was articled to a civil engineer in Exeter, where he was engaged in the construction of railways in that neighbourhood. Afterwards he became connected with Messrs. Morewood and Rogers, galvanised iron manufacturers, London; and subsequently established himself at Wolverhampton in that manufacture, which he carried on there successfully for a period of twelve years, including the manufacture of screws, nails, wire-netting, and buckets, &c. He took an active part in the Gospel Oak Iron and Wire Works, Tipton, for several years up to the time of his death, which took place at Sutton Coldfield on 17th May 1874 in his 45th year. He became a Member of the Institution in 1869.

Benjamin Dobson was born in 1823 at Bolton, where his family had carried on the business of machine makers since 1790. He entered the establishment of his father in Bolton, where he mastered the various mechanical details in the construction of cotton-spinning machinery. In 1846, after the death of his father, he entered into partnership with the late Mr. Metcalf; and the new firm of Dobson and Metcalf having constructed new extensive works in Bolton removed there from the old works. On the death of Mr. Metcalf in 1851, he entered into partnership with the late Mr. Barlow of Bolton, and the name of the firm became Dobson and Barlow, which

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is still retained. Mr. Dobson retired from the business about two years before his death, which took place at Clifton on 21st June 1874, in the 51st year of his age. His name is associated with many important inventions in cotton-spinning machinery, and the spinning trade of Lancashire is largely indebted to his firm for the rapid progress it has made during the last thirty years. In order to ensure exactness and economy in production he invented many special tools, and thus secured a widely extended reputation for the machinery made at his works. He became a Member of the Institution in 1865.

James Eastwood was born on 6th March 1808 at Alderwasley, near Ambergate, Derbyshire, and was with his father at Alderwasley Forge until twenty-one years of age, learning his trade as a hammerman. After working a short time at the Codnor Park Iron Works and at Manchester, he settled at the Mersey Steel and Iron Works, Liverpool, where he remained many years, making the large marine-engine and other forgings, which were considered enormous at that period; and inasmuch as there was no steam hammer in use then they may still excite wonder. Among many others may be mentioned the forgings for the "President" and the "Great Britain" steamships; and a malleable iron gun for the United States steam frigate "Princeton," which was turned and bored by Messrs. Fawcett Preston and Co., and was proved in 1845. The bore was 1 ft. diam. and 12 ft. length, and the weight previous to turning and boring was 12·39 tons, and 7·83 tons when finished, the weight of the shot being 219 lb.; in the proving thirty rounds were fired with charges of 30 to 45 lb. of powder. In 1847 he left Liverpool to join the late Mr. Thomas Frost of Wigan, and commenced business in Derby under the style of Eastwood and Frost, which partnership was terminated by Mr. Frost's death in 1853. He brought out several inventions, including steam-hammer motions and a hydraulic shearing press, of which last a description was given to the Institution (see Proceedings Inst. M. E. 1858 p. 70). In 1867 he with his son amalgamated their business with that of their neighbours, Messrs. Swingler and Son, the two works being

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carried on under the style of Eastwood Swingler and Co. His death took place after about a year's illness, on 17th April 1874, in the 67th year of his age. He became a Member of the Institution in 1856.

Sir WILLIAM FAIRBAIRN, Bart., LL.D., F.R.S., was born at Kelso in Roxburghshire on 19th February 1789, his father being a farmer there and afterwards land steward on an estate in Ross-shire. He received the principal part of his early education at the parish school of Munlochy near Inverness, and later from his uncle the parish schoolmaster at Galashiels. At the age of sixteen he was apprenticed to the owners of the Percy Main Colliery, near Newcastle-on-Tyne, of which his father had been appointed manager, where he remained till he was twenty-one, and formed there the acquaintance of George Stephenson, then employed at Willington Quay near Newcastle. In 1811 he went to seek employment in London, and worked at Mr. Rennie's and afterwards at Mr. Penn's at Greenwich. He was next engaged in Dublin in constructing for Mr. Robinson of the Phœnix Iron Works machinery for making nails. In 1814 he obtained employment in Manchester as a working millwright under Mr. Adam Parkinson, with whom he remained two years, and then began business on his own account. In 1817 he was joined by a former shopmate, Mr. James Lillie, and the partnership of Messrs. Fairbairn and Lillie was carried on for eighteen years. From this time a full account of his life would almost involve the history of half a century of progress in mechanical science, in the development of the productive power of Manchester manufactures, in the application of iron to the building of ships, in the adoption of iron walls on land as well as on sea for purposes of military defence, and in a wide range of invention and discovery connected with the strength of materials of construction, and the economy of motive forces. One of his earliest works was the renewal of the driving machinery in a large cotton-spinning mill in Manchester, in which he introduced light quick-running wrought-iron shafting in place of the cumbrous slow-moving cast-iron shafts that were then universal. The success

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with which this was performed, and the economy of power effected by the important improvements which he introduced, placed his firm at once in the front rank of engineering millwrights, and necessitated successive removals to larger premises. In 1826, having to fit up the water-wheels for extensive cotton-mills at Catrine Bank in Ayrshire, he introduced the construction known as the "ventilated bucket," in which the air contained in the bucket, instead of having to make its way past the water entering the bucket, quietly escaped at the back of the bucket above. In 1829 he was employed upon the Forth and Clyde Canal to discover the best means of increasing the speed of canal boats, and the result of his experiments was the establishment of light iron passenger-boats, called fly-boats, travelling at a speed which previously had not been thought possible. Having as early as 1831 built in Manchester a small sea-going iron vessel, he erected in 1836 extensive shipbuilding premises on the Thames at Millwall, where he carried on business for nearly fifteen years. It was in this yard, which was the earliest iron-shipbuilding establishment of any magnitude in England, that the experiments on the strength of iron tubes were conducted, which led to the determination of the dimensions and proportions of the Conway and Britannia tubular iron bridges, and the law by which the resistance of wrought iron to tension and compression is calculated; and to Mr. Fairbairn is due the mode of construction by a combination of rectangular cells, whereby the idea originally conceived by Mr. Robert Stephenson of using hollow structures, through the interior of which the traffic should pass, was rendered practicable in these bridges. He very early directed his attention to the strength and other properties of wrought and cast iron, and in his extensive experiments and investigations engaged the mathematical assistance of the late Mr. Eaton Hodgkinson, placing the works at his disposal, suggesting experiments of practical value, and defraying the cost which attended them; these researches were continued over a number of years. Nothing of practical value seemed to escape Mr. Fairbairn in the use and application of iron. He invented about 1836 the machine for riveting by steam power the plates of boilers, ships, and bridges.

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He improved the construction of boilers, and introduced the system of double flues and alternate firing, whereby fuel was economised and smoke consumed. He turned his attention to the causes and prevention of boiler explosions, and to the law which governs the density and pressure of steam; and in the course of his researches he discovered that the strength of boiler flues subjected to external pressure was inversely as their length, and he introduced an important improvement in their construction by the insertion of internal stiffening rings at short intervals. He was an indefatigable writer, always ready to communicate his knowledge; and his numerous publications constitute standard works of reference in mechanical engineering science. He became a Member of the Institution in 1847, the year of its commencement, and was elected President in 1854 and 1855. He contributed several papers to the Proceedings, including descriptions of the large winding and pumping engines built by his firm for the Dukinfield Colliery (1853 p. 137 and 1855 p. 177), and of the floating steam corn-mill constructed for use in the Crimea (1858 p. 155), and also of the tubular wrought-iron cranes erected at Keyham Dockyard, Devonport (1857 p. 87). He was created a Baronet in 1869, in acknowledgment of his scientific attainments and services, which were also recognised by numerous learned societies both in this country and abroad. His death took place at Moor Park, Surrey, the residence of his son-in-law, on 18th August 1874, in his 86th year.

Samuel Clough Faviell was born at Kirkby Overblows, near Wetherby, Yorkshire, on 10th July 1835, and was apprenticed to Mr. Joseph Butler of Stanningley Iron Works near Leeds. He was afterwards connected with the Kirkstall Forge Co., and eventually became the representative of Messrs. Taylor Brothers and Co., of the Clarence Iron Works, Leeds, which position he occupied till his death on 28th January 1874, in the 39th year of his age. He became a Member of the Institution in 1865.

James Fletcher, Jun., was born in Manchester in 1838, and at the age of thirteen was employed in the drawing office at

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Messrs. W. Collier and Co.'s machine-tool works in Salford, Manchester, where he had every facility for learning the business of a mechanical draughtsman, his father being then a partner in the firm. Subsequently he worked in the shops, and in 1863, when his father became the sole proprietor of the works, he was made manager, and continued in that position to the time of his death, which occurred on 1st February 1874, from the rupture of a blood vessel, in the 36th year of his age. He designed and constructed some of the largest machine-tools that have been made; and also superintended the erection of all the plant and machinery in the Imperial Marine Factory at Cronstadt, and was well known as a practical engineer in Russia and other countries. On many occasions his opinion was asked and acted upon in reference to the production of heavy work by modern systems of plant and machinery. He became a Member of the Institution in 1866.

Charles Frederick Gurden was born in Liverpool on 13th February 1843; and after being educated at St. Omer in France and also at the Liverpool College, he passed through the works and drawing office of Messrs. Forrester and Co., Vauxhall Foundry, Liverpool. When his apprenticeship was finished, he was engaged as engineer assistant to Mr. Alfred Holt, who was then constructing the first one of the single-crank compound marine engines known as the Holt engines. In 1864 he was appointed Superintending Engineer for the steam fleet of Messrs. Lamport and Holt of Liverpool, and in that capacity his whole mind was given to introduce improvements in one steamer after another, in the development of the single-crank engine, which in these Brazilian steamers has now successfully superseded the double-crank engine. In these steamers he had special facilities for testing practically the relative economy and best proportions of the details of construction in compound engines, and had made considerable progress in those subjects. In 1871, his health failing, he had to abandon engineering and to spend the winter at Pau, intending when stronger to make a business of designing marine engines for special economy, having received much encouragement

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from owners and builders. On his return to England however an affection of the eyes prevented him from using them professionally; and after a partial recovery his health again became weaker, and he died in Liverpool on 22nd September 1874 in the 32nd year of his age. He became a Member of the Institution in 1866.

JAMES INNES HOPKINS was born in Edinburgh in October 1837, and in 1858 entered the engineering business of Messrs. Snowdon and Hopkins, afterwards Hopkins and Co., at Middlesbrough. In 1865 this firm united with that of Messrs. Gilkes Wilson and Co., under the joint name of Hopkins Gilkes and Co., and Mr. Hopkins subsequently became the London director of the new company. In 1873 his health began to fail, and in consequence he went to Pau in 1874; but on returning homewards died at Paris on 22nd May 1874 in the 37th year of his age. He became a Member of the Institution in 1860.

JOHN HOSKING was born in 1839 at Attercliffe near Sheffield, and at about sixteen years of age entered the drawing office under his father at Messrs. Hawks Crawshay and Sons, Gateshead Iron Works, Gateshead, where he remained for a number of years. He was afterwards employed by Messrs. Yorke and Co. of London, partly in their office, and at other times as inspector of bridge work for a railway in Italy, for which they were the contractors. On the completion of this work he returned to the Gateshead Iron Works in 1866, to assist his father, on whose death at the end of 1871 he succeeded him as engineer of the works, and continued there until his death on 24th November 1874 at the age of 35. He became a Member of the Institution in 1873.

WILLIAM BLAKE LAMBERT was born at Berwick-upon-Tweed in 1816, and in 1836 went to London, and commenced his studies as an engineer at the establishment of Messrs. Maudslay Sons and Field. He subsequently became Chief Engineer and Managing Director of the General Screw Steam Shipping Co., the first company that undertook to carry on a regular service of steamers

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to India and Australia viâ the Cape of Good Hope; and under his management their steamships acquired a high reputation. He quitted the service of the company in 1856, and received from the Government an appointment as Engineer at Portsmouth Dockyard. In 1859 he received from the Russian Government the appointment of Chief Engineer to their fleet, which he held for seven years, returning to England in 1866. He died while on a visit to St. Petersburg, on 18th February 1874, aged 58 years. He became a Member of the Institution in 1866.

SAMPSON LLOYD was born in Birmingham on 7th June 1808, being the seventh son of Mr. Samuel Lloyd, banker, of that town. After being apprenticed at a comparatively early age to his brother at Stockton-on-Tees, he was employed in his father's bank in Birmingham; and on the death of one of his brothers he took an interest in a colliery property at Wednesbury, which had belonged to the family for several generations; this led to the establishment of the firm of Messrs. Lloyds Fosters and Co. in 1835, in which he held a fourth share. The object of the company in the first instance was to develop the colliery, by building blast furnaces and introducing improved winding and pumping machinery; and in connection with the furnaces there was a small foundry and engineering establishment, of which he undertook the management. As the railway system of the country began to be developed, Mr. Lloyd turned his attention to the manufacture of railway material; in this he was assisted by the late Mr. John Joseph Bramah, to whom he always considered that he was indebted for his first start in that branch of engineering work. Under his energetic management the business rapidly developed, and the Old Park Iron Works soon became one of the first establishments in the kingdom for the manufacture of wheels and axles and other railway material. In 1856 large rolling mills were erected for the manufacture of tyres and axles &c.; and this for many years was a most successful branch of the company's business, to which were added, about ten years afterwards, works for the manufacture of Bessemer steel in all its branches. Mr. Lloyd was always prompt to adopt

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any invention which was sufficiently developed to be applicable to his business. His firm were among the first in the South Staffordshire district to adopt the hot blast in their furnaces, and to utilise the waste gases for various purposes; and were among the earliest to introduce the improvements of the late Mr. Joseph Beattie and Mr. Mansell in the construction of railway wheels. Numerous important contracts for bridge work were executed under Mr. Lloyd's superintendence for the Indian, Spanish, and Australian railways. One of the largest works with which he was immediately connected was the new Blackfriars Bridge, London, for which his firm supplied the ironwork. Their part of the contract was executed without difficulty, but they unfortunately became guarantors for the contractors for the foundations and erection. This caused much anxiety and annoyance to Mr. Lloyd, but he persevered in spite of peculiar difficulties, which arose chiefly in connection with the unusual method adopted in the design of the work, of employing rectangular caissons of wrought iron in forming the foundation. This system had to a great extent to be abandoned, and it was largely owing to the perseverance and energy of Mr. Lloyd that the contractors were enabled to complete the work. In 1867 the business of Messrs. Lloyds Fosters and Co. was transferred to the Patent Shaft and Axletree Co., of which Mr. Sampson Lloyd became vice-chairman, and he continued to take an active part in the management till within a year of his death, which took place on 26th September 1874, in the 67th year of his age, at Areley House near Stourport, where he had recently gone to reside. Mr. Lloyd was a Member of the Institution from the commencement, having taken a leading part in its establishment; he was one of the Vice-Presidents for nine years, and an active member of the Council for ten years previously. He was chairman of the Darlaston Steel and Iron Co., and took much interest in the development of that company's property during the latter years of his life. He was also chairman of the South Staffordshire Water Works and of the Swansea Wagon Co., both of which were in a state of great depression when he took the office, and to his energy and perseverance their

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present prosperous position is largely due. During the greater part of his life he avoided public affairs, except in immediate connection with the town of Wednesbury; but after leaving that place and taking up his residence at Wassell Grove, Hagley, he became a Justice of the Peace for the counties of Staffordshire and Worcestershire. His character was one of great energy and perseverance, and of the strictest integrity. He was of a most kindly disposition, and ever ready to sympathise with the sorrows and difficulties of others, whether poor or rich. In public affairs, in business, and in private life, the same good sense and energy were manifested by him in little things as in more important matters, and were always combined with his characteristic warm-heartedness and cheerfulness; he was consequently much esteemed and beloved by all who were connected with him in his various undertakings.

JOHN MANNING was born in 1830 near Wellingborough, Northamptonshire, and in June 1846 was apprenticed to Messrs. W. and J. Galloway, of Knott Mill Iron Works, Manchester. After having completed his term of five years' service, he entered into partnership with Mr. Headly, of the Eagle Foundry and Iron Works, Cambridge, with whom he remained until 1858. In 1859 he became a partner with Mr. C. W. Wardle and Mr. A. Campbell in the Boyne Engine Works, Leeds, where he continued until his decease on 31st March 1874 at the age of 44. He became a Member of the Institution in 1859.

WILLIAM MARTLEY was born on 4th January 1824 at Ballyfallon, Meath, Ireland; his father, Mr. John Martley, being a gentleman of family in that county. Showing early a strong taste for mechanical pursuits, he was articled to Mr. Daniel Gooch, then Locomotive Superintendent of the Great Western Railway at Swindon; and on the completion of his professional studies he received an appointment on the Great Western Railway at Exeter. He subsequently held the office of Locomotive Superintendent on the Waterford and Limerick Railway, then a similar office on the

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South Devon and South Wales lines; and in 1864 was appointed Locomotive Superintendent of the London Chatham and Dover Railway, which post he occupied until his death after a short illness on 6th February 1874 at the age of 50. He became a Member of the Institution in 1864.

FREDERICK HENRY RICKETTS was born in London on 16th April 1837. Showing at an early age a taste and aptitude for the profession of engineer, and being desirous of acquiring a fundamental knowledge of its details, he first served for a year in the iron-shipbuilding yard of Messrs. Day and Summers at Northam, Southampton; and thence went as a pupil to Messrs. Liddell and Gordon, civil engineers, Westminster, under whom he afterwards acted as Resident Engineer over different railway works then in progress in South Wales, and also assisted in laying the submarine telegraph from Candia to Athens. He was afterwards employed by Messrs. Forde and Fleeming Jenkin in superintending the construction of the waterworks at Rouen in France, and assisted them in the completion of various scientific apparatus. His next and last employment was under Messrs. Siemens Brothers, for whom he laid the Orkney and Shetland telegraph cables, and aided in designing their new works at Charlton and their steamship the "Faraday." After a visit to North America to make preliminary arrangements for the laying of the Direct United States cable, he proceeded early in 1874 to Brazil, to lay a cable from Rio de Janeiro to the southern frontier of the empire; and had completed three out of the four sections of which it was to consist, when the stranding and wreck of the "Gomos" at Rio Grande, with the remainder of the cable on board, unfortunately suspended the operations. He returned to England, and was proceeding again to Brazil with a fresh supply of cable for the completion of that work, when his career was cut short in the 38th year of his age by the lamentable foundering of the "La Plata" off Ushant in the gale of 29th November 1874. He became a Member of the Institution in 1874.

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THOMAS ROSE was born in 1809, and was for many years connected with the iron and coal trades of the South Staffordshire district, being one of the proprietors of the Bradley Iron Works, near Bilston. After retiring from these works he was for the latter part of his life connected only with the coal trade of North Wales. He died at his residence in Wolverhampton on 13th June 1874 at the age of 64, after a protracted and very painful illness. He became a Member of the Institution in 1866.

JAMES SAMUEL was born at Glasgow on 21st March 1824, and after attending the classes of engineering by Professor Gordon at the Glasgow University, was articled in 1839 to Mr. Daniel Mackain, Engineer of the Glasgow Water Works; after which he held for three years the position of Resident Engineer at the printing, dyeing, and bleaching works of his father near Glasgow, for which he designed and superintended the construction of the buildings, machinery, reservoirs, watercourses, &c. In 1846 he settled in London and was appointed Resident Engineer of the Eastern Counties Railway, which position he held till 1850. It was during his connection with this railway that with Messrs. Adams and Richardson he brought out the fish-joint, which under various modifications has been adopted on all railways, and to its improvement and development he devoted years of study and labour. He was deeply impressed with the necessity of economy in railway transit, on which subject he read a paper at the Institution in 1849, and also one in 1852 on the economy of working steam expansively (see Proceedings Inst. M. E. October 1849 p. 4, and 1852 p. 27, 41). He likewise carried out numerous experiments on light engines and steam carriages, with the object of reducing the weight and cost of the rolling stock of railways, with very satisfactory results (see Proceedings Inst. M. E. June 1848 p. 8). Between 1851 and 1858 he constructed successively the Morayshire, the Newmarket, the Llanelly Extension, and the Vale of Towy Railways, and also the new stone Bridge over the river Avon at Evesham. In 1858, in conjunction with Mr. John Pitt Kennedy, he made the plans and estimates for the railway from Smyrna to Kassaba and thence to

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Ushak in Asia Minor, the former part of which has since been carried out. In 1861 he went to the United States to report upon and estimate for the completion of the Grand Rapids and Indiana Railway in the state of Michigan. He was then continuously engaged in inspecting and reporting upon various railways in Austria, France, Germany, and Russia; and in 1863 went with a party of engineers to examine and report upon the feasibility of constructing a ship canal from the port of Greytown on the Atlantic, up the river San Juan and through the lakes of Nicaragua and Managua, to the bay of Tamarindo on the Pacific; but after making a careful examination he found the cost of this line of route, as laid down by the French engineers from whose preliminary surveys the scheme originated, would be far in excess of that contemplated, and the project was abandoned. In 1864 he was appointed, together with Colonel Talcott, joint Engineer-in-Chief of the Mexican Railway from the port of Vera Cruz to the cities of Puebla and Mexico; Colonel Talcott retired from his connection with the line in 1866, and in 1869 Mr. Samuel exchanged the appointment of chief engineer to the railway for that of Consulting Engineer, which he continued to hold to the time of his death. In 1871 and 1872 he carried out a railway of 3 ft. gauge in Cape Breton for developing the extensive coal mines in that region. He died in London on 25th May 1874 at the age of 50, from paralysis of the brain, after an illness of three months, having been a Member of the Institution from 1848.

Peter Wright was born in Dudley on 15th March 1803, and in early life commenced business as a vice and anvil manufacturer, a trade which had been carried on by his family in the same place for more than a hundred years previously. He made many improvements in the manufacture of anvils and vices, all of which were successful; and this placed him at the head of the trade, as the senior partner in the firm of Messrs. Peter Wright and Sons, of Dudley and Oldbury. In 1848 he invented and made the machinery for cutting the internal screws of vice-boxes out of the solid iron, making the "solid box vice," which he was the first to

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accomplish; this he did by fixing the screw-cutting tool vertically during the cutting, so as to allow the cuttings to fall away clear of the work. In 1852 he invented the "solid anvil" with which his name is associated, and which he was the first to make all forged solid in one piece by means of dies and by turning it frequently under the hammer during the forging, anvils having previously been always built up of a number of pieces welded together. In 1862 he invented the parallel vice, and also an improved railway wheel. He died on 28th August 1874 in the 72nd year of his age. He became a Member of the Institution in 1863.

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The PRESIDENT, in moving the adoption of the Annual Report, said the earnest desire of the Council was to further the interests of the Institution, and they would be glad to hear and to take into consideration, and, if deemed expedient, to act upon the suggestion of any measures for the advancement of the Institution. He hoped the proposals contained in the Report were steps in the right direction; they were looked upon as steps only, but a beginning must be made, and if the proposals now made turned out to be successful in their actual working, that success would give an incentive for further improvement.

The motion for the adoption of the Report was passed.

The PRESIDENT announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year :—

PRESIDENT.

FREDERICK JOSEPH BRAMWELL, F.R.S., London.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, F.R.S., ...	Newcastle-on-Tyne.
THOMAS HAWKSLEY, ...	London.
JOHN HICK, M.P., ...	Blackburn.
WILLIAM MENELAUS, ...	Dowlais.
JOHN ROBINSON, ...	Manchester.
CHARLES P. STEWART, ...	Manchester.

COUNCIL.

CHARLES E. AMOS, ...	London.
E. HAMER CARBUTT, ...	Bradford.
EDWARD EASTON, ...	London.
FREDERICK W. KITSON, ...	Leeds.
WALTER MAY, ...	Birmingham.
FRANCIS W. WEBB, ...	Crewe.

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PAST-PRESIDENTS.

Ex-officio permanent Members of Council.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S., . .	Newcastle-on-Tyne.
James Kennedy, ...	Liverpool.
Robert Napier, ...	Glasgow.
John Penn, F.R.S., . . .	London.
John Ramsbottom, ...	Manchester.
C. William Siemens, D.C.L., F.R.S.,	London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., ...	Manchester.

COUNCIL.

Members of Council remaining in office.

John Anderson, LL.D., F.R.S.E., .	London.
Joseph Armstrong, ...	Swindon.
Henry Bessemer, ...	London.
William Clay, ...	Birkenhead.
Charles Cochrane, ...	Dudley.
Edward A. Cowper, . . .	London.
Edgar Gilkes, ...	Middlesbrough.
Jeremiah Head, ...	Middlesbrough.
Percy G. B. Westmacott, . . .	Newcastle-on-Tyne.

The following New Members were also declared to be duly elected :—

MEMBERS.

Capt. Carlos Braconnot, . . .	Rio de Janeiro.
Samson Fox, ...	Leeds.
George Hepburn, ...	Liverpool.
Thomas Hopkin Hosgood, . .	Merthyr Tydvil.
Antonio Gomes de Mattos, . .	Rio de Janeiro.
John Charles Raymond Okes, .	London.
Edward Platt, ...	Sowerby Bridge.

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JOHANNES ANDREAS PRIOR, . .	Copenhagen.
GEORGE STANTON PROVIS, . . .	Jumalpore, India.
FREDERICK WHITAKER SCOTT, . .	Manchester.
THOMAS BUDWORTH SHARP, . . .	Birmingham.
JOSEPH SAMUEL TAYLOR, . . .	Birmingham.
JOHN WILLIAM WAILES, . . .	Swansea.
WILLIAM WALKER, ...	Saltburn-by-the-Sea.

GRADUATE.

ARTHUR HENRY WALKER, . . .	Tipton.

Mr. J. ROBINSON moved the following resolution, in accordance with the notice given at the last meeting:—"That the Council be empowered to appoint a Meeting in each year to be held in Manchester." He observed that it was the original intention of the Institution to hold meetings regularly in the three places—Birmingham, London, and Manchester—as centres of different districts; and it was provided in the original rules that besides the quarterly meetings in Birmingham there should be in the first half of each year meetings in London, and in the latter half meetings in Manchester. There had not been the means of carrying this out, but there was now established a regular Spring meeting in London, which had proved very satisfactory and successful, and he thought a regular Autumn meeting in Manchester was desirable, and would also prove successful, and would be a satisfactory carrying out of the original intention of the Institution. Manchester being the centre of a great mechanical district, containing a large number of the members of the Institution, was specially eligible for holding one of the meetings each year, both with regard to the attendance of members at the discussions, and for the supply of papers. The resolution proposed was only permissive, leaving the carrying out to the discretion of the Council.

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Mr. C. W. Siemens seconded the resolution, and remarked that the trial of the meetings in London had been found a success in the attendance and discussions, and it seemed to him only fair to give the great northern mechanical centre also a trial. He thought Spring was the most suitable time for meeting in London, being the most attractive season on account of parliamentary and other business; and Autumn, which was not desirable for London, would be well suited for a Manchester meeting.

Mr. A. Paget cordially supported the proposal, as a trial; and suggested, as a means of enabling members who were not present to judge of the success of the meetings, that the attendance of members and visitors at all the meetings should be published.

The President remarked that in the report just read the attendances at the different meetings were recorded.

Mr. W. L. Wise supported the proposal, and remarked that there were about 70 members in Manchester, besides those in the adjoining districts.

The resolution was then passed.

Mr. A. Paget enquired whether there was anything in the rules prohibiting the publication in scientific journals of the discussions at the meetings; he did not think there was any such prohibition in the rules.

The President replied there was not any rule on the subject, and it was a matter left to the Council, by whom, following the example of the Institution of Civil Engineers and other societies, it had been decided to be not expedient for the observations made in the discussions to be published before the speakers had an opportunity of correcting them.

The following paper was then read :—

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ON JAQUES OAKLEY AND STERNE'S ELECTRO-MAGNETIC CHUCK FOR HOLDING SPECIAL WORK IN LATHES, &c.

BY MR. WILLIAM E. NEWTON, OF LONDON.

In the process of turning planing or drilling certain kinds of work, the time required for fixing the article upon the chuck of the lathe or upon the bed of the machine often greatly exceeds the time of operating upon it; and for some articles, such as thin metal discs or circular saws, the ordinary mode of holding the article is inapplicable or involves much difficulty and inconvenience. This difficulty, in the case of facing thin steel discs of 2 to 3½ in. diameter and sometimes only 1-32nd in. thickness, led to the invention of the Electro-Magnetic Chuck described in the present paper. The idea is, to convert the chuck into a temporary magnet, so that the thin steel articles when simply placed on the face of the chuck are held there by the attraction of the magnet; and when finished can be readily detached by merely breaking the electric contact and de-magnetising the chuck.

The Magnetic Chuck applied to a lathe is shown in plan in Fig. 5, Plate 1; and enlarged longitudinal and transverse sections of the chuck are shown in Figs. 1 and 2. A circular face-plate A forms the face of the chuck, which in the above-named case is 3 in. diameter; and the thin steel disc C to be operated upon is placed upon a central stud B, as these discs had each a central hole; additional studs can be fixed in the face-plate where required, for preventing the work from slipping on the chuck.

The face-plate is composed of three parts,—a central soft iron core D, an outer iron tube A surrounding the core, and an intermediate brass ring keeping them apart at the outer end. The central core D and the outer tube A are each surrounded with a coil of insulated copper wire E, and the whole electro-magnet is

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enclosed in a wood case F. One end of the inner coil is connected electrically with a brass contact-ring G fixed on the outer wood case, and the other end is connected to the outer coil, the opposite end of which is connected to a second brass contact-ring H upon the outer case. These rings are grooved, and receive the ends of a pair of metal springs J connected with the terminal wires of an electric battery, whereby the chuck is converted into an electro-magnet capable of holding firmly on its face the article to be turned or ground.

In the case already named the steel discs were ground by an emery wheel K, Fig. 5, driven at 300 to 3000 rev. per min., and mounted in a slide-rest L by which it is traversed across the face of the work. The thickness of the finished discs was accurately regulated to a uniform gauge, by means of a circular gauge-plate M turning loosely on the end of a spindle N, which is pressed forward by a helical spring, but has a very fine adjustment by means of the divided nut P. When the emery wheel has ground the disc down to the thickness of the gauge-plate, it comes in contact with the gauge-plate, and causes this immediately to spin round rapidly, and give out a ringing sound which indicates the completion of the operation. The workman then breaks the electric contact, and detaches the finished disc.

This mode of holding iron or steel articles upon a lathe chuck answered so satisfactorily in the first form in which it was applied, that its application was extended to more general purposes; but for holding articles larger than 5 or 6 in. diameter a modified construction is found more convenient, as shown in longitudinal section in Fig. 3, and in front elevation in Fig. 4. The face-plate A of the chuck is here divided across the centre by a thin brass strip S, and the two halves of the face-plate form the two poles of the horse-shoe magnet C, which is a single bar of soft iron bent up at each end, having the copper wire E coiled round its two turned-up ends. The back plate B is tapped for screwing upon a lathe; and the face-plate A and back plate B are connected together by the magnet C, which is fixed in a groove across the back plate. The

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whole is enclosed in a cylindrical brass casing F, and the two brass contact-rings H H fixed round this casing are insulated by a ring of ebonite, and are connected with the two terminal wires of the magnet coils; a groove in each ring receives one of the studs on the springs J, which are connected with the two poles of the battery. There are a number of holes in the face-plate, Fig. 4, in which studs can be fixed for preventing the article held upon the chuck from slipping on the face.

A similar arrangement is also adapted for holding work upon the bed of a planing or drilling machine, as shown in Fig. 6, in which case the brass contact-rings are dispensed with, and any desired number of pairs of the electro-magnetic face-plates are combined so as to form a surface of sufficient extent to carry large pieces of work.

For exciting the electro-magnet, any ordinary battery that will produce a continuous current of electricity can be used; but in machine shops where power can be obtained, it is more convenient to employ a magneto-electric machine—such as Gramme's, for instance—rather than a battery.

A specimen was exhibited of the electro-magnetic chuck, fitted with a small battery for illustrating its action; and samples were shown of thin steel discs that had been ground upon it, some for circular saws 4 in. diameter and 1-40th in. thick, and others $5\frac{1}{2}$ in. diameter and 1-20th in. thick, bevilled to a sharp cutting edge for cutting up india-rubber into thin strips for weaving elastic fabrics. For this purpose it was explained that the steel discs had first to be ground very accurately to a uniform thickness, and then to be bevilled down uniformly round the edge; they had to be held on the lathe chuck in such a manner as to allow of the grinding tool passing across the centre, and the electro-magnetic chuck afforded a ready means of meeting this requirement.

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Mr. W. Smith considered that so far as the chuck itself was concerned it was very ingenious, and he thought there was a large field open for the application of the plan to special descriptions of work. For any parts of delicate instruments likely to be affected by the magnetic action, such as the balance wheel of a watch, it would probably not be suitable.

Mr. C. W. Siemens had no doubt the electro-magnetic chuck would prove successful for such purposes as that referred to in the paper, namely for holding a thin disc or any other light article upon the revolving chuck of a lathe for polishing. But no information had been furnished as to the actual force of adhesion with which the work was held by this means; and he should be glad if some particulars could be given in regard to that point. No doubt if thin discs, like those now exhibited, had only to be polished or lightly ground up, the adhesion on the electro-magnetic chuck would be sufficient to hold them; but judging simply from his own general experience in connection with the force of magnetic adhesion, he thought this would probably not be sufficient to admit of taking a good cut off the work, and it would be necessary to resort to the ordinary mode of fixing the work with cement upon the face-plate of the lathe. It was a question which mode of fixing would be found the cheapest in the long run; but he thought there could be little doubt that for any light kinds of work, such as polishing or grinding, the electro-magnetic plan might be made efficient.

With regard to the method of making the electrical connection from the battery to the revolving chuck, by means of the sliding contact of a single stud or finger bearing in a groove upon the chuck, he should have some doubt as to the efficiency of this mode of making the contact; for in sliding along the groove the chances were that only one point of the sliding piece would touch, and this point might be disabled by having become covered with some non-conducting substance, such as metallic oxide, in consequence of which the continuity of the current might cease and render the magnetic adhesion uncertain. From his own

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experience he had found that a single sliding contact could not be depended upon, and he therefore generally multiplied the number of touching points. No doubt a dynamic magneto-electric machine was a better means of producing an electric current, especially in a machine shop where steam power was at hand, than the employment of a battery. There was perhaps one objection to the arrangement of lathe headstock shown in the drawings, in the fact that this must necessarily be very heavy, and would have to be driven at a very great speed for polishing or grinding the discs held upon it; there would consequently be considerable loss in having to start and stop it so frequently for changing the work upon it.

Mr. J. Robinson noticed that there were a number of stud holes in the face of the chuck, arranged in two diameter lines at right angles to each other; and if these were used for preventing the disc that was being ground from slipping upon the face of the chuck, it seemed to imply that the adhesion produced by the magnetism was not sufficient to prevent slipping. He should be glad to know whether the bevilling of the edge of the cutting discs exhibited was done with the same fixing of the discs upon the magnetic chuck as the grinding of the flat portion; for it was evident that the greatest amount of strain tending to make the work slip would occur in the bevilling process, particularly when the grinding wheel or tool reached the edge of the disc. It appeared to him also that there would be some difficulty in getting the disc fixed exactly central and true on the chuck; with discs of this kind it was just as important for the cutting edge to be accurate as for the thickness of the disc to be so, and in the bevilling of the edge this could only be accomplished by having the disc fixed so as to run perfectly true, as well as exactly in the centre of the chuck. In reference to the speed of revolution of the chuck itself, he did not think this need be very rapid, if all that was wanted was merely to rotate the work so as to bring every part of the surface opposite to the grinding wheel or other tool employed; the wheel being driven at the

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required speed for performing the work, it would not be necessary for the lathe chuck itself to revolve very rapidly.

Mr. E. A. Cowper observed that the force of the magnetic adhesion was certainly not very great, and he should be glad to hear something about its actual amount, and whether the vacuum principle would not be as effective. Respecting the mode of making the electric contact from the battery to the revolving chuck, he suggested that if a brush of wires were used, the contact would be improved; this was the plan adopted in connection with the employment of Gramme's magneto-electric machine for other applications.

Mr. W. Smith mentioned, in reference to the amount of adhesion obtained with the magnetic chuck, that he had seen it in operation in London, and had been informed that ¼ inch cut could be taken in a planing machine fitted in that way; but although a powerful Gramme's magneto-electric machine was being employed, the tool instead of taking ¼ inch cut off the work stuck fast in it, and the work shifted on the table of the planing machine. It might be that the Gramme's machine was possibly out of order; but he believed 1-16th inch would be nearer the maximum depth of cut than ¼ inch.

Mr. A. Paget thought it could hardly be seriously intended to suggest the application of the magnetic chuck for planing machines, as the magnetic adhesion could scarcely be expected to give sufficient hold for taking a cut in planing without a most wasteful expenditure of power. The difficulty of getting light discs, such as those exhibited, accurately centred on the magnetic chuck, so as to run true and give a perfectly true cutting edge in the bevilling, had already been alluded to; and another and much greater difficulty, which he had experienced in the use of a great number of very thin circular saws, only 7-1000ths inch thick, was that if the thin disc happened to be not perfectly flat,

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but slightly warped or buckled, as was usually the case after hardening, it would be impossible to make it flat by any amount of grinding on the magnetic chuck, because when placed upon the chuck it would be partially flattened for the time by the magnetic attraction, but would spring back again to its former curvature as soon as removed from the chuck. The use of a vacuum, which had been suggested, he considered would involve the same objection; but this was not the case with the plan of bedding the work in cement, which held it in its original form and thus allowed of grinding it perfectly flat and true.

Mr. C. W. Siemens said, with respect to the question of the amount of adhesion produced by an electro-magnet, this was dependent within certain limits upon the weight of the armature, and not upon the extent of the surfaces in contact. The total pressure holding the armature upon the poles of a magnet was only about four or five times the weight of the magnet, if the weight of the armature was sufficient, or less if insufficient, so that the pressure to be dealt with could be but a very moderate one; and the sliding friction between the surfaces in contact amounted to only 1-8th or 1-10th of the pressure holding them together. Moreover a certain mass was required in the armature itself, in proportion to the weight of the magnet, and the force of adhesion would be greatly diminished if this mass were not sufficient; consequently with a very thin disc on the chuck, the adhesion would probably be very inconsiderable.

The President regretted that the author of the paper was prevented by illness from attending the meeting, and that Mr. Oakley was also unable to be present. From the observations which had been made, it seemed that for heavy work the electro-magnetic arrangement would hardly be practicable, while for delicate pieces there would not be mass enough in the work itself to get the requisite amount of adhesion for performing any but the lightest operations; and it had been rightly pointed out also that if a thin plate were at all buckled, it would be sprung flat when placed upon

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the magnetic chuck, but would recover its previous form on being released. The subject of the paper however was an interesting and acceptable one, even though the plan might only be successful in special applications; and he proposed a vote of thanks to the author, which was passed.

The following paper was then read:—

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ON THE MANUFACTURE AND TESTING OF PORTLAND CEMENT, AND THE MACHINERY USED IN ITS PRODUCTION.

By Mr. HENRY FAIJA, of London.

The various purposes for which Portland Cement is now used, and the great extension of its application, as it enters more or less into all engineering operations, render its manufacture a subject of importance to all engineers; more especially as the quantities of inferior cement that are met with make it imperative that the user should be able to distinguish the bad from the good, in order that its employment may not incur the risk of causing unsatisfactory work, as well as give a bad name to a cement that is one of the best ever introduced, when properly made and properly used. In this paper therefore it is proposed to give a resumé of the Manufacture and Testing of Portland Cement, together with a description of the Machinery used in its production; through the kindness of Mr. Borders of the West Kent Portland Cement Works at Aylesford, near Maidstone, the writer has been able to secure specimens of the raw materials and of manufactured cement in various forms, for illustrating the paper.

Composition of Portland Cement.—The chemical analysis of Portland cement gives about 80 per cent. of carbonate of lime, the remaining 20 per cent. being composed of silica, iron, and alumina. In practice these proportions are roughly attained by a mixture of chalk with mud obtained from the banks of the Thames and Medway, (or in some cases in lieu of the mud, gault clay,) in the proportions of about 4 of chalk to 1 of mud or clay, according to the ingredients each material used is found to contain. These are mixed in what are known as wash mills, and the result called "slurry" is run

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into large reservoirs or "backs," and allowed to settle; it is then dried, and afterwards calcined at a high temperature, and eventually ground between millstones to the requisite fineness. In Fig. 10, Plate 6, is shown a general plan of works erected to turn out 360 tons of Portland cement per week.

Wash Mills and Elevators.—The wash mill, shown in Fig. 1, Plate 2, is a circular pan about 18 ft. diameter and 4 ft. deep, usually built of brick, with a brick bottom, sunk into the ground and puddled on the outside. On one side of the pan is an opening, or in some cases an overflow; in the case of an opening this is covered with perforated zinc or wire gauze forming a sieve, so as to allow of nothing passing but the chalk and clay which are held in solution. In the centre of the pan is a revolving vertical shaft, to which is bolted a framework carrying the harrows; these have their tines fixed at different distances from the centre, care being taken to arrange them so that no two shall immediately follow each other in their course, or in other words be the same distance from the centre. The tines are usually made of wrought iron about $1\frac{1}{4}$ in. square, and their distance apart must vary according to the size of the chalk to be washed, chalk in large pieces of course requiring the tines to be placed further apart than when small refuse chalk is used. The centre shaft, being driven at about 18 rev. per min. by means of bevel wheels fixed on the top and connected to the engine by a driving strap, takes the harrows round, and thus mixes or washes the chalk and mud. Some manufacturers prefer to have the gearing arranged underneath, in order to allow of a perfectly open space over the pan; but in that arrangement the difficulty of getting at it for oiling, and the quantity of dirt which works into the bearings, quite obviate any advantage gained by a clear space above, as the overhead gearing if properly arranged need in no way interfere with the workmen. Outside the pan is the well A, into which the washed clay and chalk run through the sieve B. If two or more wash mills are used, it is advisable to connect them all to one well, so that one pump may lift all the slurry from the different mills up to the trough C leading to the backs. One of the great difficulties attending this part of the

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manufacture of Portland cement is the continual choking of the pump; an elevator is therefore fast superseding it, and can claim advantages in almost every respect. The elevator is simply a succession of buckets fixed upon a continuous band revolving round an upper and a lower drum, as shown at E E; the buckets dip into the well A as they come to the lower drum, and take up the slurry, which as they turn over at the top drum is thrown into the leading trough C. The size and number of the buckets depend on the quantity of slurry to be lifted per hour.

Washing.—The process of washing or mixing is simple: the chalk and clay, measured by the barrow load, are tipped into the pan at the point D, Fig. 1, and the water is admitted at the point F, in the proportion of about two of water to one of chalk and clay. The tines in their revolution throw the chalk and clay about, and thereby thoroughly mix and disintegrate them; and being thus held in solution the material passes through the sieve or over the overflow, as the case may be, into the well A, in the form of slurry, which is then lifted by the elevator or pump to the leading trough C and thence passes to the back.

Backs.—The backs are reservoirs usually made large enough to contain about 600 cubic yards of slurry; thus, on the calculation that two cubic yards of slurry yield one yard of finished cement, and that a back will take from six to eight weeks to settle, it is easy to determine the number required, the depth being about 4 ft. and the sides built sloping, as shown in Fig. 2, Plate 3. It is advisable to have as much "back" room as possible in proportion to the rest of the works, as it must be borne in mind that, although the mills may be worked day and night, the slurry can only settle by gradual subsidence; and pushing a back, *i.e.* putting the slurry on the drying floor too wet, necessitates a greater amount of fuel to dry it, and thus a loss. When a back is filled, it is allowed to settle, the chalk and clay sinking to the bottom; the water is then drawn off by means of the sluice at A, Figs. 2 and 3, and the back is refilled, the water being again drawn off when it is settled, and so on until the back is full; the slurry is then dug out and laid on the drying floor.

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Drying Floor.—The drying floor, Figs. 5 and 6, Plate 4, is simply a floor formed of fire-clay tiles or iron plates, with an arrangement of flues underneath, stoked at one end, and meeting a cross flue at the other end conducting to the chimney shaft A. In most cement manufactories the drying floor is constructed with coking ovens underneath, so that, while drying the slurry, coke to be used in the kilns is manufactured; but in the writer's opinion this is a questionable economy, as the quantity of coke thus produced is nothing like sufficient to supply the kilns, and he therefore prefers a simple fire-grate in place of the coking oven, as shown in Figs. 5 and 6. With that arrangement the cheapest fuel can be used, less care is required in stoking, and the loss from bad coke is avoided; the cost of construction is considerably reduced, besides which the repairs needed to a coking oven are considerable, as against almost none in the other case. In consequence of these considerations the simple fire-grate, when looked at in regard to economy, compares favourably with what at first sight appears an excellent arrangement. It is advisable to construct the floor of such a size as to dry sufficient slurry for one day's work, so as to avoid loss of labour and fuel; it should be covered with a light roof supported on columns, the sides being left open to allow the moisture evaporated from the wet slurry to escape, but at the same time protecting the floor from the weather. The slurry as it is brought from the backs is laid on the drying floor in a layer about 5 in. thick, which by the evaporation of the moisture becomes reduced to about 4 in. when dried; it is then ready to be loaded into the kilns to be burnt.

Kilns.—The kilns are circular in plan and usually of about the form shown in Fig. 4, Plate 3; but the shape varies considerably in different districts and according to the fancy of different manufacturers. The principal requirements are that they should have a good draught, and that their inner surface should be so formed that the clinker as burnt shall fall to the bottom evenly and without clinging to the sides; for when the clinker hangs, its weight necessarily brings down some of the inner casing of the kiln, and the kilns under the most favourable circumstances form one of the most

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expensive items in a Portland cement manufactory, costing as much as from 30 to 40 per cent. per annum of their first cost to keep them in repair. Perhaps the most economical size of kiln to adopt is one large enough to burn from 20 to 30 tons of finished cement. For a 20-ton kiln a capacity of about 70 cubic yards is requisite, though many manufacturers, by what is called "topping," *i.e.* adding fresh coke and dried slurry as the clinker sinks, burn 30 tons in a kiln of that size. As a kiln takes one day to load, one day to burn, one day to cool, and one day to unload, the number of kilns required is for four days' work, that is, four times the number required for one day's burning; but as repairs are more or less always necessary, it is well to provide a sufficient number of kilns to do from four and a half to five days' work. The kilns are charged through the loading holes at the points B B, Fig. 4, with alternate layers of coke and dried slurry, in the proportion of one of coke to two of dried slurry; and when properly burnt the kiln is opened and allowed to cool, and as the clinker is drawn it is taken to the crusher to be broken into pieces about 1 in. cube, preparatory to being passed through the millstones. The kiln is drawn by knocking out the firebars, and the charge falling into the ashpit is taken out and carried to the crusher.

Crushing Rollers.—Various means of breaking the clinker are adopted, from the rough and somewhat expensive way of breaking it by hand with a hammer, to the most elaborate stone-breaking machine. Without going to the expense of such a machine, but yet improving on the former method, a pair of crushing rollers, as shown at R R in Fig. 7, Plate 5, may be adopted with economy. The rollers, made of cast iron with chilled faces, are formed with longitudinal grooves along their entire length, and are placed at such a distance apart as to break the clinker to the requisite size. A hopper is placed over them, leading the clinker between the rollers, which, by revolving in opposite directions, crush it as it falls between them; the clinker is then led by an inclined plane into a trough, to be lifted by the elevator E into the hopper H supplying the millstones. The elevator is on exactly the same principle as that already described for lifting the slurry; but the

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buckets in this case must be considerably heavier and stronger, and should be lipped with steel in order to withstand the roughness of the broken clinker.

Hopper.—The hopper H, Fig. 7, leading to the millstones, should be made with the sides sloped to a sufficiently steep angle to allow of the clinker falling easily to the bottom and into the shaking trough T. This trough, which is made to shake by means of a cam C fixed on the centre shaft of the millstones, allows the clinker to fall gently in between the stones, and the shaking prevents the clinker from blocking the lower mouth of the hopper.

Millstones.—The millstones, generally from 4 ft. to 4 ft. 6 in. diameter, have an outer casing of iron. The clinker falling into the centre of the top stone is taken in between the stones, and is gradually ground and led to the outer edge by grooves, such as are usually cut in millstones; it thence falls into the outer iron casing, from which a spout S leads it to any convenient place where it can be collected in barrows and laid on the warehouse floor.

Power.—It is found convenient to drive the millstones, crusher, and clinker elevator by one engine, driving the mill shaft by means of friction or toothed wheels direct from the main shaft M of the engine; this is placed under the herse floor, which should be about 6 ft. above the warehouse, as shown in Fig. 7, Plate 5. By this arrangement any number of stones may be driven by connecting them to the shaft by bevel wheels; the bearings &c. are all covered up, and the dust from the cement is kept from them. A good inclination can be given to the spout S leading from the millstones, thus enabling the ground cement to clear them easily. The elevator and crusher may be driven from the mill shaft or from the main shaft of the engine as found most convenient. Each millstone requires from 8 to 10 H. P. to drive it; the power to drive the elevator and crusher must of course depend on the amount of work which they have to do, but it may be allowed that for a four-stone mill about 40 H. P. will be required to drive the stones, elevator, and crusher. It is preferred by the writer, whenever possible, to drive the wash mills and slurry elevator by

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separate power from the rest of the machinery, because, besides the advisability of sometimes placing them at some distance from the mill and warehouse, it is always well to be able to continue filling the backs even when the rest of the works are temporarily stopped, and by this means that can be done without loss. The power required to drive a wash mill of the construction shown in Plate 2, with its elevator, would be from 8 to 10 H. P., and it would wash from 80 to 90 tons of slurry per day.

Remarks.—A general description of the process of manufacture having now been given, a brief reference is desirable to those parts where great care is necessary in order to ensure the cement being of good quality: and firstly the wash mill deserves attention. As this is where the ingredients ultimately formed into cement are first incorporated, it is of the greatest importance that the proper proportions of chalk and clay should be used, and it is therefore imperative that frequent trials should be made of the slurry as it leaves the wash mill, so as to ensure the backs being filled with a uniform quality. The chalk and clay should also be occasionally analysed, in order to correct any variations that may occur in either.

The drying process being merely an intermediate stage, in fact scarcely anything beyond assisting in abstracting the moisture from the slurry, does not call for particular attention; but the kilns again show the necessity of careful manipulation. Care must be taken that the kiln is burnt evenly throughout, and when unloading, the clinker should be carefully sorted, and all yellow or softly burnt pieces should be returned to be placed on the top of the next kiln and reburnt; and only that clinker which is perfectly burnt should be passed to the crusher to be prepared for grinding.

Having passed through the millstones, the ground cement is laid out on the warehouse floor and allowed to cool, being occasionally turned over; this mixes the different days' work and gives uniformity to the cement produced, and also allows any particles of lime still unslacked to slack by exposure to the air. The cement should be left in this way for a considerable time before

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being packed, and it will then have become thoroughly cooled and there will be but little fear of its "blowing" when used; curiously enough, it will also have increased in weight and bulk, so that it is obviously to the advantage of the manufacturer to follow this course, though the great demand for cement, the space it occupies, and other trade reasons often prevent its being thoroughly carried out.

General Quality.—The quality of Portland cement is usually determined by its colour and its weight, in combination with its fineness; besides which it is required to withstand a certain tensile strain when made into a "briquette" or small testing block, Figs. 8 and 9, Plate 5, and to show no signs of either expansion or contraction in setting. Though at present considerable diversity of opinion exists as to what the tests for fineness and tensile strength should be, still, when it is remembered that the cement should be of one uniform good quality, capable of being gauged with two or three or even more times its bulk of sand for use, and that when the weight and fineness are in such proportions as to give a good carrying capacity for sand, the tensile strength is as a matter of fact assured, it then becomes possible to arrange such tests as will meet most requirements.

Tests.—In colour Portland cement should be of a dull bluish grey, and should have a clean, sharp, almost floury feel in the hand; a coarse gritty feel denotes coarse grinding, and the finer a cement is ground the more it approaches to an impalpable powder. It should weigh from 112 lb. to 118 lb. per striked bushel, and should be so fine that 80 per cent. will pass through a sieve of 2,500 meshes to the square inch; when moulded into a briquette and placed in water for seven days, it should be capable of resisting a tensile strain of from 300 lb. to 400 lb. per sq. in., and should during the process of setting show neither expansion nor contraction.

Weight and Fineness.—A light cement, *i.e.* one weighing from 100 lb. to 108 lb. per bushel, is invariably a weak one, though it may be of the requisite fineness; at the same time a heavy cement if coarsely ground is also weak, and will have no carrying capacity

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for sand. As the more the clinker is burnt the harder and heavier it becomes, and therefore the more difficult to grind in the millstones, the heavy cements are almost invariably coarse ones; and as an under-burnt cement from its softness will be ground fine enough, but will be deficient in weight, it will be seen that the weight, unless taken in conjunction with the fineness, is no test as to the quality of the cement. It will therefore be found advisable to adopt a medium weight such as already mentioned, namely from 112 lb. to 118 lb. per striked bushel, as with that weight a finely ground cement may be secured, and one that will suit most engineering and building operations.

Tensile Strength.—For the strength test a briquette of the form shown in Figs. 8 and 9, Plate 5, is usually adopted, the breaking area or neck being 2·25 sq. in. The cement should be gauged with as little water as possible in a mould of the requisite shape, and in twenty-four hours it should have set sufficiently to be removed from the mould, and should be placed in a tank of water, where it should remain for seven days; at the end of that time it should be tested, and should then be capable of resisting a tensile strain of from 300 lb. to 400 lb. per sq. in. of breaking area. This, though a universally adopted test, is in the writer's opinion open to objection on the ground that the cement is never used in a similar manner, and is in point of fact never, except in rare instances, subject to the strain of direct tension; though as a comparison between the strength of different cements it may be of use, still he thinks that some other test should be adopted, more in keeping with the manner in which the cement is ultimately to be used.

Expansion.—This defect, due to the cement being too hot, may be traced to various causes. It is met with most frequently in very heavy cements, from the fact of their containing in their original crude form a larger proportion of lime, which does not get thoroughly done away with in the process of burning in the kilns; small particles consequently remain unslacked, which slack when the cement is gauged with the water for use, and these eventually "blow" in the work, causing a general expansion. An under-burnt

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cement, or one that is used too soon after it has left the mill and before it has had time to cool, will show the same defect. The most simple test for detecting expansion in a cement is to make small pats with a trowel, about 3 or 4 in. square, and place them in water when set sufficiently, where they should remain a few days. If the cement be good, they will show no alteration in form; but any cracks showing on the edges, or other deviations from the original shape of the pats, indicate that the cement is of this expansive nature, and therefore not to be trusted. But because a cement will not stand this test, it is not in all cases to be condemned as useless, as its expansive or blowing property may be attributable simply to its being used too soon after leaving the mill; in which case a proper process of cooling, by laying it in a thin layer on a dry floor for a short time before using it, will correct the defect.

Contraction.—This defect, due to the cement being over-clayed, is so seldom met with, that it is needless to say more than that it may be detected by a similar test to that for expansion.

In the limits of this paper the writer has only been able to describe the process of manufacture as carried out on the Thames and Medway; but although in different localities and countries the crude materials may be treated in a somewhat different manner, still the result is the same, and the cement, if good, should be able to stand the preceding tests. He trusts however that the paper may be the means of drawing attention to a subject which is of great importance to all those using Portland cement.

Mr. Faija exhibited a series of specimens obtained from the West Kent Portland Cement Works, illustrating the several stages of the manufacture described in the paper, from the crude materials employed to the finished cement produced; together

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with specimens of the testing blocks or "briquettes" which had been broken in the usual way under the tensile test. With regard to the statement that a coarse cement was also a weak one, he explained that the deficiency of strength was not directly owing to the coarseness, but to the fact that in a coarse state the cement when it came to be used would not stand the proper admixture of sand requisite for economic use.

Mr. E. A. Cowper said he had seen the manufacture of Portland cement according to the description given in the paper, which was essentially a wet process, and was the one carried out universally on the Medway. Another process in use in Germany, as he was informed by a Dutch engineer, was a half wet and half dry one, and the kilns employed were those known as Hoffmann's.* These kilns were said to be used there to great advantage, but they were not used at present he believed in this country for the manufacture of Portland cement, though there were a number of Hoffmann's kilns in use here for burning lime and bricks &c.

With regard to the "backs" or settling reservoirs employed in the wet process, he enquired what size these were required to be in proportion to the number and size of the kilns used. He supposed there were gangways at the ends of the backs, for wheeling the stuff out to the drying floors in emptying the backs. There were several plans for utilising the waste heat passing off

* The Hoffmann kiln consists of a number of chambers arranged in a circle, and leading one into another, with valves and flues leading to a central chimney, so that any one chamber may alone be connected to the chimney. In the normal working condition there are two or three chambers filled with materials and burning, and being supplied with coal through small holes in the top; and the heat and products of combustion pass through the several next chambers filled with cold materials till they arrive at a partition or stop, and then pass up the chimney. The air for the combustion of the coal enters from the outside through a doorway left open for the purpose, at a distance of several chambers from the fire; and these intervening chambers being full of materials that have been burnt and are still hot, the air becomes very highly heated before arriving at the chambers that are burning and into which coal is being fed. Thus the air gets heated before combustion, and the materials are dried and heated before being burnt.

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from the kilns by conveying it under the drying floors; but where the floors were heated by a fire applied directly beneath, as shown in the drawing, close to the floor and without any intervening protection, it seemed to him that the brickwork would suffer considerable wear and tear; and he should be glad to know how the brickwork was found to stand in that mode of heating. For crushing the lumps of clinker drawn from the kilns, the ordinary crushing rollers only had been described; but he thought a Blake's crusher and a pair of edge runners were considered much better for the purpose; on the Medway he believed edge runners were generally preferred to rolls for crushing the clinker previous to grinding by millstones.

Another mode of manufacturing cement was by the dry process, in which very little water was used, and consequently there were neither wash mills, slurry, pumps, nor backs. He exhibited a series of samples obtained from the Rugby Portland Cement Works, where this dry process of manufacture was carried on remarkably well. The materials there employed were the blue lias limestone of that district, and a very small quantity of the intervening clay; these were obtained from an open working or quarry, and having been ground extremely fine between millstones, were slightly damped and put into a pug mill, from which the mixed material was forced out in the form of rough bricks. These bricks after being thoroughly dried were put into a kiln; and the burnt clinker drawn from the kiln had almost the whole of it the fine dark blue or slate colour of the specimen shown, with scarcely any white or yellow portions. The clinker was then crushed and ground, and was laid out on the floor, the common notion being that it required much cooling; this however he considered was not the case, and he believed the correct explanation was that, if the ground cement contained a little lime not thoroughly united with the clay, this lime, when the cement was mixed with water for use, would become slacked and by its consequent expansion would have a tendency to burst the cement; and the object therefore of spreading the cement out upon the floor immediately after grinding was to prevent this liability, by allowing any such small portions of lime

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that remained unslacked to become thoroughly slacked by taking up carbonic acid from the atmosphere. The cement thereby increased slightly in weight; and it also absorbed a very little moisture from the air, being not quite so dry after grinding and lying on the floor as when taken out of the kiln. When proper care was exercised in the earlier stages of the manufacture, it was possible to take the ground cement direct from the millstones for immediate use, without fear of its bursting when set. In reference to the statement given in the paper, that expansion was "met with most frequently in very heavy cements, from the fact of their containing in their original crude form a larger proportion of lime, which does not get thoroughly done away with in the process of burning in the kilns," he did not understand how any of the lime could possibly be got rid of in the burning, and he did not think any of it passed away, even if there was an excess of lime above the proper proportion. It was the presence of uncombined lime, he believed, that was injurious; and the ground cement should therefore be laid out on the floor, and allowed to lie there until it had become sufficiently weathered by exposure to the air.

With regard to the testing of the finished cement, the standard of tensile strength now adopted by the Metropolitan Board of Works was 787½ lb. for briquettes of 1½ inch square section; this standard was much higher than that first adopted, namely 400 lb., and it was only due to Mr. Grant, of the Board of Works, to say that the great improvement in Portland cement of late years had been very much influenced by his exertions in that direction. The test mentioned in the paper of 400 lb. per sq. in. of breaking area would be equivalent to 900 lb. on the section of 1½ inch square; but a great deal of the cement made on the Medway was now up to 1100 lb., and all of it above 1000 lb. on that section. Nineteen tests made of the Rugby cement at intervals during the whole of last November gave an average of 1248 lb. as the tensile strength of briquettes of 1½ inch square section. He showed also samples that he had tested of the same cement, which had borne a very considerably higher tensile strain; one piece that had been made

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two years and eight months broke at 2330 lb., and many others at about 1800 lb., while pieces that had been made seven or eight days and had lain six days in water broke at 1400 lb. on the section of $1\frac{1}{2}$ inch square. The weight of the cement in these cases was about 112 to 120 lb. per bushel. At the Rugby Portland Cement Works was made also a very quick-setting cement, weighing only about 90 lb. per bushel, and breaking with about 700 lb. per $1\frac{1}{2}$ inch square, of which a specimen was shown; it was intended for light work where a quick-setting cement was desirable.

Mr. C. Cochrane enquired whether any attempt had been made to work the kilns continuously in the manufacture of cement.

The President said the continuous or running kiln was a very common mode of burning.

Mr. C. W. Siemens mentioned that a kiln had been erected to his design in the chalk district in Surrey, which worked continuously; it was worked with gas, and had proved very satisfactory, having the advantage that none of the clinker drawn from it was ever mixed with imperfectly burnt lime or clay. With regard to the exposure of the ground cement to the atmosphere, by spreading it out upon the floor, he agreed in the explanation which had just been given, that this process could only mean that some of the lime being uncombined with clay required time to take up carbonic acid from the air, thereby undergoing the very slacking which would otherwise cause expansion in the cement when used.

In some of the specimens exhibited of the briquettes which had been broken in testing, he noticed the curious circumstance that the fracture did not occur exactly at the smallest section, but the material broke across a somewhat larger section, near the shoulder or point where the sudden change of sectional area took place. This subject had been investigated by the President in an interesting paper read by him at the Exeter meeting of the British Association, in which he had shown that, where a sudden change in dimensions took place in any piece of material exposed to a strain, the weakest point occurred at that part.

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Mr. E. A. COWPER mentioned that the briquettes which he had seen tested had many of them broken in the centre, and not at the shoulder.

Mr. FAIJA, in reply to the enquiry about the size of the backs, said the size shown in the drawing was 110 ft. length by 60 ft. width, giving 6600 sq. ft. area; there was one back to a week's work, that is, one back contained slurry enough for a week's supply of the kilns. The proportionate number of backs to kilns depended on the size of each; it was necessary to have sufficient back room to do from six to eight weeks' work, and a sufficient number of kilns to do from four and a half to five days' work. With respect to the firegrate of the drying floor, there was a firebrick arch immediately over the fire, which protected the floor from direct contact with the flame.

In the testing of the briquettes made on the Medway, of which specimens were exhibited, there had not been the means of increasing the weight in that case beyond 1000 lb.; one of the specimens, which had been seven days in water, broke at that strain, and another, which at first did not break at 1000 lb., afterwards broke when that weight had been kept on it for ten minutes. With respect to the position of the fracture, he had seen the briquettes break straight across the centre in testing. The lighter cement that had been mentioned for quick setting was not intended, he supposed, for mixing with sand or other materials, but only for use neat where rapidity of setting was of more importance than strength, and it should perhaps not be classed therefore as Portland cement. The method of manufacture that had been referred to as in use in Germany was the same he supposed as that introduced there by Mr. Lipowitz some ten years ago.

Mr. E. A. COWPER said in that process part of the material was worked dry and part of it wet; they were mixed together and were made up into rough bricks, which were burnt in the kilns, and were afterwards finished by crushing and grinding. The light quick-setting cement that he had referred to had been

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found to stand a strain of 700 lb. per briquette, and was not intended to be mixed with Portland cement, or used in place of it, but was for light work.

The PRESIDENT said the present subject was one on which they had not previously had a paper; and as one great business of engineers was to find out how best to unite together the several parts of a structure, any information was acceptable which would throw light upon the improvement of the quality of so important a uniting material as was Portland cement. Having himself had something to do with this subject, he would say that the old process and the one generally pursued was that described in the papor. But some backs which he had seen, rather deeper and more nearly square in form than those shown in the drawing, had in the middle an upright spindle carrying a trough projecting 30 ft. on each side, like a gigantic Barker's mill, delivering the slurry from the ends of the arms as they revolved, and thus filling the back rather more uniformly. It had been found that the chalk and clay composing the slurry tended to separate while settling in the backs, the two materials not going down together in consequence of the difference in their specific gravities; and in deep backs it was therefore requisite to provide against this in emptying them, by taking from the top and bottom together, in order to get the quality regular. It had been mentioned in the paper that pumps had not been found to answer for lifting the slurry from the wash mills to the backs, on account of continual choking; but he believed when made with spherical valves of large size they had given no difficulty. It had also been stated that from 8 to 10 H.P. was required for each pair of millstones; in point of fact he had found that it took 1 Ind. H. P. to grind 1 bushel of cement per hour. If a preliminary crushing machine was used to crush the clinker in preparation for grinding by the stones, just as much power altogether was consumed in the whole mill as in grinding without previous crushing; but the work was better done by crushing before grinding, and the millstones did not wear out so soon. Crushing rollers appeared to him to labour under a disadvantage,

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as they were always struggling to bring a larger quantity through than they could pass, and thus their surfaces acted like a constant break resistance to the driving power; but with a Blake's crusher very little power went to waste, and this machine he knew worked most satisfactorily.

Although the usual mode of testing cement by tensile strain was objected to in the paper, and a compression test appeared to be considered rather as the one that was required, it was admitted that probably the tensile test might be taken as sufficient for comparing one cement with another. This he believed to be the case, and that if the two kinds of strength did not go together exactly, they did so very nearly. The two best papers that he knew on this subject were those read to the Institution of Civil Engineers in 1865 and 1871 by Mr. Grant, one of the Engineers to the Metropolitan Board of Works. They contained really everything that was known upon the testing of cement; and both kinds of tests having been made by the writer, a comparison of the results showed that the tensile strength varied in very closely the same ratio as the resistance to compression. Thus in two experiments in which the resistances to compression were 6,725 and 3,928 lb. per $4\frac{1}{2}$ sq. in. area, the corresponding tensile strengths were respectively 413 and 218 lb. per sq. in., showing a very fair agreement in the proportion.*

Hoffmann's kiln was largely and successfully used on the Continent, and he did not see why it should not be used in this country; for it seemed to him that, with the mode of working the kiln described in the paper, the fuel must be a great expense, being charged in alternate layers with the dried slurry to be burnt. It was a common practice to use the waste heat from the kilns for the drying floors; but when the fuel was intermixed with the slurry throughout the whole mass in the kiln, the air entering at the bottom of the kiln, although it became converted into carbonic oxide by the combustion of the fuel and by afterwards passing through the heated fuel, was immediately so diluted with the carbonic acid driven off from the slurry that it could not be

* Proceedings Inst. C. E. vol. XXV page 106, table XLII, lines 11, 12.

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further utilised as a fuel, as it was then impossible to re-ignite the gas that passed off from the top of the kiln, overburdened as it was with such an excess of carbonic acid, and thus much of the effect of the fuel was lost; there was consequently much to do in the way of improvement with regard to the kilns. The periodic kiln he believed was the one which gave the most certain results, and yielded the heaviest cement from the quantity of slurry charged into it; but the running kiln was the most economical in fuel, on account of the heat never being let down for drawing the charges. The latter kiln was indeed used to a great extent, one of the oldest and largest cement works in this country employing 75 per cent. of running kilns and only 25 per cent. of periodic kilns.

He moved a vote of thanks to Mr. Faija for his paper, which was passed.

The Meeting then terminated. In the evening a number of the Members dined together in celebration of the Twenty-eighth Anniversary of the Institution.

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PROCEEDINGS.

April 1875.

The General Meeting of the Members was held at the Institution of Civil Engineers, London, on Wednesday, 28th April, 1875; Frederick J. Bramwell, Esq., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

George Allan, ...	Sheffield.
John Henry Beckwith, ...	Manchester.
Isaac Bradley, ...	Birmingham.
Richard Charles Braithwaite, ...	Wednesbury.
Frederick Cooper, ...	Bombay.
Edward Coward, ...	Manchester.
William Dickinson, ...	London.
Edward Bayzand Ellington, ...	Chester.
Thomas William Gardner, ...	Bombay.
Robert Gordon, ...	Calcutta.
Walter John Hammond, ...	Brazil.
James Mansergh, ...	London.
William Harry Stanger, ...	London.
Arthur James Stevens, ...	Newport, Mon.
Frederic John Ramsbottom Sutcliffe, .	Bradford.
George Tangye, ...	Birmingham.
William Steele Tomkins, ...	Manchester.

The following paper was then read:—

SOME NOTES ON THE EARLY HISTORY OF RAILWAY GAUGE.

By Mr. WILLIAM POLE, F.R.S., of London.

The object of the present paper is to offer to the Institution a contribution to the history of Railway Gauge. It was the author's privilege, a few years ago, to be called on to write the chapter on the gauges in the life of the late Mr. I. K. Brunel; and in preparing himself for this work he had occasion to study many documents, not generally accessible, bearing on the early history of the subject. He conceives that some of the facts therein disclosed have, in recent discussions, hardly received the attention they are entitled to, and he therefore thinks it may be useful and interesting to put them on record.

In the first place it is desirable to take a brief view of the manner in which that element of railway design called the "gauge" first came into existence. Almost as early as wheel carriages were used, it must have been remarked that the power required to draw them diminished in proportion to the smoothness and hardness of the road on which they travelled; and this led to the laying down of longitudinal tracks of some smooth material, such as broad plates of wood or stone. The latter form of this primitive device was for many years used on the Commercial Road leading to the East and West India Docks, and may still be seen on London and Westminster bridges and elsewhere. These tracks had necessarily to be fixed at such a distance apart as would suit the wheels of the vehicles intended to travel upon them, and this was the first approximation to a definite gauge.

In process of time however, when iron was substituted for the material of the tracks, it became necessary to define the gauge with greater precision. The stone slabs had been made of considerable

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breadth, to provide for the variable distance between the wheels of the vehicles; but to give this great breadth of plate in the more costly material, iron, would have been inconvenient and expensive, and it was found preferable to make the plates narrower, and to restrict their use to vehicles the wheels of which were a uniform distance apart—a measure easily arranged in the mining districts, where large numbers of vehicles belonged to one owner, and where the same wagons had always to run over the same ground. But under this altered condition it became necessary to adopt some contrivance for keeping the wheels from running off the tracks; and this led to the introduction of the guide or flange, running longitudinally along the outer edge of the track plate, forming the old tram-road, the immediate precursor of the railway.

With this system the adoption of a uniform gauge was imperative; but probably no consideration was given to the question what the gauge should be. The wagons ordinarily in use were simply adapted to the tramroad by making them uniform, and such a width of roadway was adopted as was found to be most suitable for them.

When experience had proved the increased capabilities of the new road, it was found that a further beneficial alteration could be made. The wagon wheels had hitherto been capable of running either on the tram or the ordinary road; but as the traffic increased, it was found desirable to set apart vehicles for the new road only, and this gave the opportunity of placing the guiding flange upon the wheel instead of upon the road—a great improvement, inasmuch as, while it answered the purpose equally well, it very much simplified the form of track. The rail thus became what it is now, merely a narrow face or edge of iron, projecting upwards from the road; this was in its first days called an "edge rail," to distinguish it from the flat plate or tram. The gauge under this construction remained unchanged, as the existing vehicles were used with merely alteration of their wheels. In many cases the wheels were so made that they might run either on the edge or tram roads, when both existed in the same districts, as shown in Fig. 2, Plate 7.

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When Mr. George Stephenson took up the subject of the locomotive engine, with the view of adopting it as the mode of haulage on the railroads of the Northumberland collieries, the gauge of the lines in the district had been already fixed. On the earliest tramroads laid down, probably the ordinary road vehicles had been used: these determined the distance apart of the tram plates; and when the special wagons were made with flanged wheels the same width was adhered to. In laying out the Stockton and Darlington line (1821-25) Mr. Stephenson saw no reason to depart from the gauge he had previously used; and indeed, as it is on record that some of the wagons to be used on the line were brought from the Northumberland collieries,* probably the facility of interchanging the vehicles was one reason that determined the similarity. In this way the first important railway in England came to be formed to the gauge of 4 ft. 8½ in., not from a choice of this width on the ground of any peculiar advantages, but from the mere fact of its already being in existence elsewhere. It has often in later days excited astonishment that so odd a dimension as 4 ft. 8½ in., should have been chosen for such an important datum; but really there was no consideration about the matter. No one at that period could have anticipated that the width of the little colliery tramways would afterwards prove to be of such immense consequence to the world.

The success of the Stockton and Darlington Railway led to the project of the line between Liverpool and Manchester; and when this was laid out in 1826, as no fault had been found with the gauge of the model line, no reason appeared why it should not be adhered to, particularly as it was desirable to preserve uniformity, in order to facilitate the transfer of engines, carriages, and wagons between different lines. Hence the same gauge was adopted as on the Stockton and Darlington. When the Grand Junction to Birmingham, joining on the Liverpool and Manchester, was laid out, the same width was necessarily adopted; this was followed also by the London and Birmingham, and thus the 4 ft. 8½ in. gauge became established as the normal one for that part of the country.

* Smiles's Lives of the Engineers, Vol. III, p. 165.

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The Liverpool and Manchester Railway was opened in 1830, but immediately on its being used for public traffic, a difficulty arose which had never been met with on railways before: the vehicles were found to be too narrow. To illustrate this, and to explain clearly how the evil was provided against, it is necessary to go back to a time before the introduction of railways, and to notice the kind of vehicle used on common roads. Long experience appears to have settled the general type of wheeled vehicles to be as represented in end view in Fig. 1. It will be seen that the chief characteristic of this type is that the body of the vehicle is placed between the wheels, coming down close to the axletree. This mode of construction gives obvious and great advantages in a mechanical point of view. It combines a large wheel with a low centre of gravity, and thus secures a minimum resistance to traction, combined with a maximum breadth of base and steadiness of position. In all railway vehicles used before the opening of the Liverpool and Manchester Railway this type was adhered to. An engraving published at Darlington (exhibited to the meeting) shows both the passenger carriages and goods wagons originally adopted on the Stockton and Darlington line, all of which, it will be seen, have the narrow body placed within the wheels. The well-known wagons for coal, called "chaldron wagons," numbers of which are still running on the northern colliery railways, as shown in Fig. 3, are exact copies of the original vehicles used for the same purpose. No inconvenience had hitherto resulted from the narrowness of body consequent on this construction. The Stockton and Darlington line had been intended almost entirely for the haulage of coals; other goods were quite exceptional, and the conveyance of passengers had been no part of the original plan, being only thought of during the progress of the works.

But with the Liverpool and Manchester Railway a new state of things arose. This line opened a much more general traffic, embracing light bulky goods and passengers, which required for their fit accommodation a large amount of room in proportion to their weight; and as soon as the line began to be worked in earnest,

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the want of space at once made itself felt. The available width between the wheels was limited to about 4 ft. 6 ins., and to carry in this width a large load of cotton wares, or a good number of passengers, required an inordinate length of the carriages, and indeed of the whole train. In fact, as already stated, the carriages were found too narrow, and an increase of width became an imperative necessity. But what was to be done? The gauge limited the breadth between the wheels, and as this gauge had now become the standard for long lengths of new line, a widening of the gauge presented appalling difficulties, which, in that infant state of railway enterprise, forbade the thought of such an alteration.

To remedy the evil, the following expedient was hit upon by some ingenious person, whose name has not descended to posterity. It was reasoned that as the resistance on a railway was so much less than on a common road, and as the surface was so much more even, the advantages of the large wheel and of the low centre of gravity might be relinquished for the sake of obtaining increased width without altering the gauge. With this view therefore a new type of vehicle was designed, in which the wheels were kept small, and the body was raised so that it might be widened out, projecting on each side over the tops of the wheels, as shown in the diagram, Fig. 4. To support this better, the axle was also lengthened, and the bearings were put outside the wheels. The earliest description of this form of wagon is contained in the second edition of Wood's "Practical Treatise on Railroads," published in 1832, about two years after the opening of the Liverpool and Manchester Railway. In this (Plate III) Mr. Wood shows a vehicle with a raised platform overhanging the wheels, and adapted for carrying loose boxes of coals; adding in the description:—"Although the drawing shows only the form of boxes used for the conveyance of coals, yet it will readily occur that the form can be varied to suit the carriage of any kind of articles; the framework or body of the carriage being raised above the wheels, the breadth can be extended to any width which the distance between the railways (*i.e.*, between the up and down lines of road) will admit."

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It seems clear from this, that the introduction of the high body overhanging the wheels was contemporaneous with the commencement of the traffic on the Liverpool and Manchester Railway, when the inconvenience of the narrowness of the gauge began to be felt; and the type so introduced has since become the standard one for railway vehicles of all kinds. But the change on the Liverpool and Manchester Railway was not unattended with difficulty. The overhang had not been provided for in laying out the line, and the limitation alluded to by Mr. Wood at the end of the extract, namely, of the width between the up and down lines, came into play. In the first instance the inner rails of the two lines were laid only 4 ft. $8\frac{1}{2}$ in. apart; probably in order to make the one 4 ft. $8\frac{1}{2}$ in. road-gauge serve both purposes, and avoid the occasion for a second gauge for the width between the up and down lines. But when the vehicles were widened, those in the up and down trains came inconveniently and dangerously close to each other in passing, and it was found necessary, a few years after the opening, to relay the lines further apart, which not only gave greater safety, but allowed of a still further overhang. The interval was thus settled at 6 ft., which it has ever since remained.

It was in this way that the railway system became burdened with an abnormal type of vehicle peculiar to itself, inherently defective in a mechanical point of view, and differing essentially from that which the experience of the world in all preceding ages had established as the proper one for wheel carriages. It is quite certain that men like George and Robert Stephenson must have seen the defects of this construction, but they were helpless; the unhappy narrow gauge was extending by miles upon miles every day in all directions, and to alter that was beyond their power. All they could do was to accept things as they were, and make the best of them, by improving as much as they could the capabilities of the imperfect system; and this they undoubtedly did very effectually.

At this point however stepped in a young man of genius, who determined to make a vigorous effort to get rid of the difficulty by striking at once at the root of the evil, and widening the gauge. A

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year or two after the first development of the defect, Mr. I. K. Brunel was called on to design the Great Western Railway, and in a report to the directors of that company, dated October 1835, he recommended that it should be constructed on a much broader gauge than that adopted in the North of England. Unfortunately no copy of this report, so interesting in a historical point of view, can be found; but from subsequent documents still extant, there can be no doubt as to the nature of the arguments he used. He perceived that the device adopted to gain width by a raised and overhanging body involved mechanical disadvantages, to which he attached more importance than hitherto. He looked forward to a great future development taking place upon railways, and a great increase of speed and traffic being effected upon them; and he conceived that the power of getting diminished traction by large wheels, and increased steadiness by a low centre of gravity, would be as much to be desired on railways as it had always heretofore been on common roads. He therefore made up his mind that the proper method of obtaining the width was by the more radical measure of widening the gauge; he says :—"Looking to the speeds which I contemplated would be adopted, and the masses to be moved, it seemed to me that the whole machine was too small for the work to be done, and that it required that the parts should be on a scale more commensurate with the mass and the velocity to be attained."* Hence the width between the rails being, so to speak, the fundamental dimension of the "whole machine," on which the development of all its parts must depend, he proposed to begin by the enlargement of this dimension, it being obvious that this must be done at first, if it was to be done at all. He conceived that the whole of the parts of the railway and of its rolling stock would be susceptible of continual though gradual improvement, and he considered it highly advisable in the outset to remove what appeared a great obstacle in the way. He pointed out a great many advantages that would arise from the widening of the gauge, particularly in the construction of the engines, and in obtaining generally reduced resistance, greater power and speed, greater

* Evidence before Gauge Commission, 1845, 3924.

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carrying capability, and greater steadiness; and, as is well known, his counsels prevailed, and it was determined to take the bold step of departing, on the Great Western lines, from the gauge already established in other parts of the country.

Mr. Brunel had then to determine what the new gauge should be; and in this he was guided by the principle already mentioned of getting the bodies of the vehicles completely between the wheels. The width of the body would be determined by the broadest article ordinarily requiring to be carried; this was a private carriage, the width of which was generally about 6 ft. 6 in. To get such a body between the wheels, would require a width of 6 ft. $10\frac{1}{2}$ in. to 6 ft. 11 in. between the rails; but 7 ft. allowed of its being done easily, and therefore this dimension was fixed on by Mr. Brunel as the standard gauge, as shown in Fig. 5. There has been much misunderstanding as to the motives which originally induced him to propose the change of gauge, and they were unfortunately lost sight of amid the multiplicity of details involved in the subsequent discussions. He has been generally charged with a mere desire to make a bigger and grander railway than anybody else, and probably this is the notion of most people who look at the thing now. It is however a pure fiction, and a great injustice to him. His motives were much more creditable, and such as did honour both to his indomitable energy and his great and far-seeing mechanical knowledge; and it is only just to the memory of a great man that the true explanation should be circulated more generally in the mechanical world.

It may naturally be asked however, why, if it was Mr. Brunel's design to return to the road type of carriage, this was not done on the Great Western lines. The history of this point is somewhat obscure. It is certain that vehicles were made with the bodies within the wheels, and many such may be still seen on the broad gauge lines; but it must be admitted that Mr. Brunel never fully carried out his principle in practice. The change back from the abnormal to the normal type was too sweeping to be hastily adopted; and hence, although the wheels were enlarged, the overhang was in most cases still retained. At a later period, a desire to get still

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greater width in the carriages perpetuated the type, and so it has remained in use on broad as well as on narrow gauge lines, as shown in Figs. 6 and 7. It is clear however that by the 7 ft. gauge Mr. Brunel retained the power of reverting to his original proposition at any future time, should the desire for greater speed and larger wheels ever render it desirable.

It does not come within the province of this paper to follow further the history of the gauges, or to do more than allude briefly to the great controversies that ensued. The author may say however, that having had occasion to examine fully and carefully (for the purpose already mentioned) the particulars of these controversies, he conceives the following propositions to be fairly established. The discussion embraced two great points of controversy, essentially distinct, namely: 1st, the comparative merits of the broad and narrow gauges respectively; and 2nd, the effects of a break of gauge.

On the first point the author conceives that the superiority of greater breadth of gauge was conclusively proved, both by reasoning and by experience. Indeed the arguments of the narrow-gauge party seldom called this in question. It would have been impossible that men like the Stephensons should seriously argue that a narrow base, a high centre of gravity, and a small wheel were advantageous in wheel carriages. What they tried to prove, and did prove, was that the established 4 ft. $8\frac{1}{2}$ in. gauge was sufficient for the traffic of the country; and hence they argued it was unnecessary to disturb the existing state of things.

The second point, that of the break of gauge, was in another category. The Stephenson party argued that it would be an enormous evil, which the Brunel party denied. There can be no doubt whatever that on this point the Great Western party were wrong, as they are now finding to their cost; for so intolerable is the evil of the break that it will probably soon lead to the entire abandonment of the broad gauge. There is however a great misapprehension as to the cause of the change. Many people suppose it is owing to the broad gauge having proved inferior to

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the narrow; but this supposition is entirely without foundation. No such inferiority was ever shown; on the contrary, the experience of long years' running fully bears out the advantages Mr. Brunel claimed:—greater capability, greater power, greater speed, and greater steadiness, and all with no sacrifice of economy. The cause of its abandonment has been the evil of the break, and that alone.

It would be curious to speculate on what would have been the present state of railway locomotion if the gauge had originally been fixed wide enough to allow of the true mechanical type of vehicle being retained. The author ventures to think, for his own part, that the carrying capacity, speed, comfort, safety, and economy of working would have been much greater than at present, and would have been alloyed by no corresponding disadvantage. The only reasonable objection that could be thought of would be the difficulty of sharp curves; and this would certainly have been got over, long before now, by the return to the *loose wheel*, another feature of the old common road vehicle, which is undoubtedly superior on mechanical principles to the clumsy railway practice of fastening both wheels upon the axle. Is it not possible that some Brunel of the future might, if favoured by circumstances, make as great an advance on present locomotion as we have made on that of fifty years ago, by restoring the mechanical advantages of which the present generation has been deprived through the unlucky copying of the Northumberland coal wagon?

The author has no wish to revive a gauge discussion, but it is reasonable to draw some inference on the subject generally. The railway type of vehicle has become so familiar that people have forgotten it arose out of the narrowness of the gauge, and have acquired the habit of considering it as an essential feature of railway construction. Nay, even by some strange perversity, the very defects of the plan have been exalted into merits, and it has been seriously proposed to make them worse still. Would any one, with this history before him, believe that a great economical policy had been based on the unmechanical proposal to push the

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wheels still closer together under the width of a carriage body? Yet the records of the last few years show that this has actually been done. It is said a narrow gauge is cheaper; but this argues simply a misunderstanding of what gauge means, and what significance it has in railway construction. Supposing the character of the rolling stock to be first determined, as it must be determined, to suit the traffic, it can make no material difference whether the wheels are 7 ft. or 4 ft. $8\frac{1}{2}$ in. or 2 ft. 6 in. apart; for the cost of the permanent way and its supports must depend on the weight to be carried, while that of the overworks can only be governed by the dimensions of the loaded vehicles, into neither of which elements does the gauge necessarily enter. It is right no doubt that under certain circumstances railways should be made cheaply; but in order to get cheapness there is no necessity to increase the present mechanical defects by narrowing the gauge. The author is sorry to say he believes the late official Indian metre-gauge movement will be pointed at by posterity as a blot on the mechanical character of the British nation. It will not only show, as Oxenstiern said, "with how little wisdom the world is governed;" but it will serve as an illustration, added to many others, of how, in spite of the general spread of scientific knowledge, the most incomprehensible delusions may prevail.

Mr. Pole exhibited a photograph of the original locomotive engine and carriages on the Stockton and Darlington Railway, and pointed out that all the carriages used in the earliest period of that line, including the passenger coaches as well as the chaldron wagons, were of the ordinary road type, the body of the vehicle being entirely within the wheels. The overhanging body was introduced subsequently, not having at that time been contemplated.

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The President remarked that the paper now read, without rendering it necessary to go into the battle of the gauges again, brought forwards the engineering proposition that there were dangers and difficulties incident to having the body of a vehicle overhanging the wheel base, and that it would be more mechanical to have such a width of wheel base as would admit of the body being within it. Looking at the fact that there had been, as pointed out in the paper, suggestions for further narrowing the gauge, this was a point which he thought might be discussed with benefit to engineering science.

Mr. E. A. Cowper said the present paper appeared to him rather like a chapter out of the life of the late Mr. Brunel; and had it been simply brought forward in that character, he should have preferred not to go into any discussion or comparison of the merits of other men, in describing the scientific capabilities of one in particular; but the subject being professedly the early history of railway gauge, he considered there was something to be said on the subject. The impression conveyed by the paper seemed to him to be that what the Stephensons did in connection with railway gauge was done without much consideration, but was happily attended with good luck, they themselves having been "helpless" to alter the then existing circumstances of the gauge. It did not appear to him however that the circumstances had wanted altering, for he believed the right step had been taken in determining upon the 4 ft. $8\frac{1}{2}$ in. gauge, which had held its own very well indeed; and there were a great number of considerations which rendered it in his opinion a much more convenient gauge than a very wide one would be. In manufactories for instance, a gauge of say 7 ft. was so very inconvenient, on account of the curves and the wagons taking up so much room, that there had often been hesitation about laying a branch line of railway into factory works. Another disadvantage was that with many sorts of materials the large broad-gauge wagons could not be loaded full, either because the articles themselves, as in the case of cheeses for instance, could not be packed to a sufficient height for making up the full load

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without crushing those at the bottom; or because in many manufactories it was very inconvenient to wait until such a wagon was loaded with a sufficient quantity of materials at one time for filling it properly full, and it was much more handy to fill smaller wagons and to send them away as soon as filled.

The chief consideration was of course the working of the line, and especially the cost of working as affected by the gauge adopted. He did not think it was correct to say that a man of genius had overcome the difficulty under which the Stephensons were labouring in consequence of the narrowness of the gauge. Unfortunately it did not appear that the alteration to the broad gauge had proved successful; not only had very large sums of money been expended upon its establishment, but also upon its abolition, and it was now being everywhere removed and replaced by the narrow gauge. Instead therefore of the Stephensons having been "helpless" to deal with the difficulties attendant upon the already existing 4 ft. 8½ in. gauge, the fact appeared to him to be that they were called upon to use their judgment in regard to that gauge, either to reject it or to accept it; they gave their judgment in its favour, and carried it out deliberately, and it had proved eminently successful; and it seemed a mistake to say that they simply took things as they found them in regard to the adoption of the gauge. The cost of working the broad gauge had been proved repeatedly to be greatly in excess of that of the narrow; and the broad gauge had failed not only on account of the break of gauge, which, as admitted in the paper, had proved so intolerable, but also on the ground of expense.

With regard to some of the early plans recommended by Mr. Brunel on the Great Western Railway, one of the first was to have 4 ft. wheels instead of 3 ft., in the expectation of going proportionately faster without increase of friction; but the axles and journals had to be made larger in the same proportion, and when the axles of the 4 ft. wheels on the broad gauge were made proportionate to those of the 3 ft. wheels on the narrow gauge, there was no gain in reduced friction of the journals. With bodies and bearings inside the wheels, the bearings must be much larger,

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and would cause much more friction, and the bodies would be much smaller than the base could well carry. Another idea was to make the line dead-true, as nearly as possible like a Whitworth surface plate. The line was made with longitudinal timbers tied down by piles 16 ft. apart, and carefully packed between with gravel. Then there was a kind of grinding machine, which was intended to go over the line and grind the surface of the rails dead-true from end to end, the idea being that on this true surface the carriages with 4 ft. wheels would run very easily. In imagining however that the carriages could be got to run so very easily, it appeared the resistance of the air must have been rather overlooked; and that this had been the case was seen from the design of some large engines made at the time, for instance the "Hurricane" and the "Thunderer." The "Hurricane" had spur wheels multiplying the motion three times, so that the piston speed might be kept low; and so little weight was thought to be needed upon the driving wheels that the engine was set on one carriage and the boiler on another, showing that the traction of the train was expected to be very light. The "Ajax," an engine of the ordinary type, had 10 ft. wheels and only 14 in. cylinders, and the stroke instead of being the usual 18 in. was reduced to 14 in., so that the piston might go at a slow speed with a high speed of train. It was expected that the small cylinders, such as were used in the old-fashioned small engines for ordinary trains at a moderate speed, could drive 10 ft. wheels and draw a heavy train; but the engine simply failed to do so, and would only draw a single carriage; it took several miles to get up speed, and it was ultimately put on one side, being like a racehorse incapable of taking any load. The first broad-gauge engine that went at a good speed and did good work was the "North Star," which happened to have been made in Stephenson's factory, though not designed there. It had large cylinders and moderate-sized wheels, and was able therefore to do the work of pulling a good heavy train; it was a very efficient engine, and many had since been made after that style. With higher speeds the increased resistance of the air had of course to be overcome, and this had been

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successfully accomplished on the narrow gauge by increasing the power of the engines, and particularly by increasing the pressure of steam, which had been the means of enabling the narrow-gauge engines to attain as high a speed as those on the broad gauge. Since this had been accomplished, the claim of the broad gauge to the high speed attained by the very large engines used upon it fell to the ground, because the narrow-gauge engines also went at an equally high speed; so that there was no further use for the excessive outlay upon the working of the broad gauge. The natural consequence had been, as predicted by many, that the broad gauge was being swept away. The experience obtained as to the comparative working of the two systems was by this time so great, that he was surprised to hear such praises bestowed upon the broad gauge, especially at a time when it was being finally abandoned.

Mr. Joseph Armstrong remarked that the gauge question had already been discussed for more than thirty years, and he thought it would probably be a long time before it was decided whether the narrow or the broad gauge was really the best. With regard to the gauge of the colliery lines in the North, from which it was said in the paper that the present narrow gauge had been taken, the line on which the first locomotive engine was run was of 5 ft. gauge, and this was the colliery branch from Wylam, where George Stephenson was born, to Lemington; the engine itself, called the "Puffing Billy," which he well remembered seeing at work on that line, was made in 1813 by Blackett of Wylam, having been designed by his engineer Hedley, and it continued running, or part of it did, from that date until 1862; it was now preserved in the South Kensington museum. There were other lines in connection with the Wylam line, which were also 5 ft. gauge. The very first locomotive for the Wylam line was built in 1804 by Trevithick of Cornwall, who he thought had scarcely had justice done him, and it was made for a 5 ft. gauge, as shown by a drawing now in his own possession; but it never got on the line, and was sold he believed to drive a foundry blowing-fan at Gateshead, and had continued at work there for that purpose until very recently.

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Stephenson's engine on the Killingworth line, for a 4 ft. $8\frac{1}{2}$ in. gauge, was made in 1814. It was a singular fact too that the original gauge on the Stockton and Darlington line was not 4 ft. $8\frac{1}{2}$ in. but 4 ft. 8 in. The Liverpool and Manchester Railway was 4 ft. $8\frac{1}{2}$ in., and then the Stockton and Darlington was altered to the same, because vehicles coming from the 4 ft. $8\frac{1}{2}$ in. gauge had some difficulty in getting over the narrower line, particularly at crossings and curves.

Having himself gone to the Liverpool and Manchester line in 1836, he was acquainted with the construction of the early vehicles referred to in the paper, and he believed the credit of the over-hanging body and outside bearing was due to Mr. Henry Booth, the secretary of that line, and Mr. John Gray, the mechanical engineer. That construction was first carried out in the second and third-class carriages, which being painted a blue colour formed what was generally called the "blue train." The wagons at that time, of the same construction, were fair-sized vehicles; and he remembered that on one occasion with those wagons two engines took a whole shipload of cotton in two trains from Liverpool to Manchester; the load amounted to from 800 to 1000 tons, and the engines had to be assisted up the Whiston incline by a bank engine. He did not think the carriages designed at that time by Mr. Booth and Mr. Gray had been improved upon to the present day, except that they had been made a little larger; each compartment in the first-class carriages held six persons then as now, the main difference being that the cubic contents of the present carriages were somewhat greater, in consequence of there being a little more height and width. Those early carriages had also laminated bearing buffing and draw springs, the ball-shackle screw-couplings, and the yellow grease; and these things had continued from that day to the present.

For the last twenty years he had been engaged upon the mixed broad and narrow gauge of the Great Western Railway, and had therefore been able to form some idea as to which gauge was the best, commercially speaking. He did not think it could be stated with correctness that the cost of working the broad gauge exceeded so largely that of the narrow gauge. No

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doubt the larger vehicles were heavier, but the difference thereby occasioned in the working cost was only to the extent of the increase of weight. If the expenses of the broad gauge were taken for a number of years during Mr. Brunel's life and under the management of Mr. (now Sir Daniel) Gooch, he thought it would be found that the working expenses of the broad gauge compared very favourably with those of the narrow. Taking the cost of locomotive power in proportion to the earnings, he believed it had been shown by the published half-yearly statements that the Great Western Railway worked their broad gauge up to a certain time at a less cost per cent. upon the earnings than any narrow-gauge line in the country.

With regard to the early large locomotives that had been referred to, he believed the design of these was due not to Mr. Brunel, but to Mr. T. E. Harrison, from whose plans the "Hurricane" and the "Thunderer" had been constructed, having the boiler on one carriage and the engine on another. It was quite correct that the best broad-gauge engine of that time was the "North Star" and other engines of that class, built by Stephenson from drawings made by Sir Daniel Gooch previously to his going upon the Great Western Railway. Those engines he believed were not designed specially for the Great Western Railway, but were made, three of them at all events, for South America.

Mr. F. W. Webb could confirm what had been stated by Mr. Armstrong with regard to the gauge of the Wylam line, which was now being altered by the present proprietors, Mr. John Spencer and others, to 4 ft. 8½ in., because of the difficulty of not being able to transfer the chaldron wagons from one gauge to the other. It would also be remembered that the first portion of what was now the Great Eastern Railway had been originally put down and opened as a 5 ft. gauge, and a quantity of the rolling stock was worked on that gauge, and was altered afterwards to the 4 ft. 8½ in. gauge. The Crewe and Chester line had been made originally 4 ft. 9 in. gauge, and he recollected the engine wheels used to be turned with thick flanges on purpose to work that line as a district by itself, until the gauge was subsequently altered to the 4 ft. 8½ in.

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With regard to the alteration made in the distance between the up and down roads, which had been referred to in the paper, on several portions of the Liverpool and Manchester line there was still the old 4 ft. $8\frac{1}{2}$ in. distance between the up and down roads; and on the Newcastle and Carlisle Railway he had noticed that the same was the case on a portion that he had recently been over. He was under the impression that the object was to have the means of working between the up and down lines on any emergency; and he had heard the same reason assigned also in other similar instances.

With respect to the difficulty of getting a sufficiently powerful engine on the 4 ft. $8\frac{1}{2}$ in. gauge, with sufficient extent of bearing surface between the axleboxes and horn plates, the most recent engines on the London and North Western Railway had bearing surfaces larger than any broad-gauge engines, and were working with unusually little wear; with journals of 9 in. length, there was as much as 112 to 120 sq. in. area of bearing surface between the axlebox and the horn plate on each side. This he considered a step in the right direction, causing a considerable reduction in the expenses of working the 4 ft. $8\frac{1}{2}$ in. gauge; some of the engines had been running from 43,000 to 44,000 miles up to the present time, and there had been no necessity yet to touch the axleboxes in any part. He had been enabled to obtain the extra length of bearing without at all interfering with the simplicity of the motion or requiring the use of weigh-bars to get at the valve-spindles.

Sir John Coode thought there was some mistake as to the gauge of the Stockton and Darlington line having been different from that of the Liverpool and Manchester; for he had been told by Mr. George Stephenson himself that the gauge on the Liverpool and Manchester line was, so to speak, a matter of accident; that there was no question raised about what the gauge should be upon that line, but that it was taken for granted, and that, when the platelayers who had previously been employed on the Stockton and Darlington line went down to lay the rails, they took with them the gauge they had already used on this line, along with the rest of their tools.

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With regard to the early large locomotives on the Great Western Railway he had thought it was Mr. Timothy Hackworth who had had to do with them, either as designer or as builder; he had himself been on the "Hurricane," and recollected the boiler being on one carriage and the engine on the other. The grindstone which had been referred to for grinding the rails to a true surface had certainly been brought to bear for that purpose; but the centrifugal force soon caused it to fly to pieces, and no more was heard of it. The piles on which the longitudinal sleepers were laid had many of them been driven by himself, and he had afterwards had either to pull them up again or to cut off their heads; for in a very short time the road became so uneven by settlement between the piles that the carriages undulated in a most uncomfortable and even dangerous manner in running over it.

Mr. Joseph Armstrong said his authority for the statement about the gauge of the Stockton and Darlington line having originally been 4 ft. 8 in. was Mr. Timothy Hackworth's son, Mr. John W. Hackworth, who had lately told him that he had frequently altered the wheels of vehicles built for the 4 ft. 8½ in. gauge to the 4 ft. 8 in. gauge of the Stockton and Darlington line. Mr. Timothy Hackworth had been the locomotive superintendent of that line, and his son had been his assistant, and had been for more than thirty years in the district. The "Hurricane" and "Thunderer" engines had been built by Hawthorn, not by Hackworth; and the driver who came with them from Hawthorn's works was his present foreman at Oxford.

Mr. J. W. Barry supposed any vindication of Brunel's remarkable mechanical talents was unnecessary at the present time; what had been stated with regard to the grindstone and other early schemes might be perfectly true, but he did not think it wise to go into such matters now, nor to try to find out errors committed in the early days of railways, either by Brunel or by the Stephensons. One point alluded to in this discussion had been already cleared up with regard to the relative advantages of

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the broad and narrow gauges, namely, the question of the working expenses; for it had been stated by Sir Daniel Gooch, and had never been contradicted, that the cost of working the traffic on the broad gauge, particularly in the case of goods and mineral traffic, was less than on the narrow gauge; and he thought it was obvious that the proportionate dead load of a broad-gauge truck must be less than that of a narrow-gauge truck.

The question of loose wheels upon railway axles was one to which he considered mechanical engineers might well direct their attention. There could be no doubt that for a railway vehicle to have both wheels fixed upon a rigid axle, and for the axles to have no means of accommodating themselves radially to curves, was a most unmechanical arrangement, and a disgrace to engineering science. In going round curves it must inevitably occur that one or other of the wheels was not rolling but sledging, absolutely destroying and tearing the surface of the rails. The working expenses were largely increased from this cause, which accounted for the rapid destruction of the rails and the constant wear and tear of the rolling stock. There could be no reason he imagined why this state of things should continue to exist, and it only required that the attention of mechanical engineers should be directed to the matter in order to devise a satisfactory construction of loose wheel and axlebox which would get over the difficulty. If this could be done, it was certain that the duration of the rails would be very much prolonged, the wear and tear of the rolling stock would be greatly reduced, and much larger profits would be earned than at present.

Mr. J. Robinson remarked that Mr. Brunel was sometimes regarded as having introduced the broad gauge merely for the purpose of making a larger railway than any before; but he thought it might be very well to remember that many railways in other countries had been made, differing from the primary English gauge of 4 ft. 8½ in., and subsequent to its adoption; and an enumeration of the principal gauges might perhaps justify, if it required any justification, Mr. Brunel's attempt to improve

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mechanically the gauge of this country. In Holland there had been in early days a gauge of 6 ft. 2 in., after the existence of the 4 ft. $8\frac{1}{2}$ in. gauge in England. In Ireland a 6 ft. gauge had originally been laid down in Ulster, with the view of increasing the carrying capabilities of the vehicles; but the same circumstances that led to the alteration from 7 ft. in England to 4 ft. $8\frac{1}{2}$ in. occurred in Ireland, and accordingly the wide gauge was afterwards reduced to 5 ft. 3 in., a railway commission having decided that 5 ft. 3 in. was a good gauge for Ireland. For India it had been decided by a commission that the gauge should be 5 ft. 6 in. All this pointed, he thought, to the fact that the 4 ft. $8\frac{1}{2}$ in. gauge was accidental, rendered so perhaps by the circumstance mentioned in the paper, namely the previous existence of a great number of colliery wagons in the North which were made to that gauge. In South America a 5 ft. 3 in. gauge had been adopted, corresponding with the Irish; and in Spain a gauge of 5 ft. 6 in., corresponding with the Indian. None of those countries had followed the 4 ft. $8\frac{1}{2}$ in. gauge. In Russia an approximation to it had been made by the adoption of a 5 ft. gauge; and it had been said that this was adopted from military considerations, in order that the break of gauge at the frontier might present an obstacle to any invasion of the country. In India an attempt at reaction from the 5 ft. 6 in. gauge had taken place, by the introduction of the metre gauge of 3 ft. $3\frac{3}{8}$ in., with the object he supposed of getting a cheaper railway. A narrow strip of land and a small gauge of railway would of course cost less than a broader strip and a wider gauge; but this was not the question to be considered; the real question was what would be for the ultimate advantage in regard to facilitating the traffic of the country. It seemed to him a grave mistake to perpetrate a break of gauge, after the example afforded by England of reducing the gauge from 7 ft. to the inconvenient gauge of 4 ft. $8\frac{1}{2}$ in., simply to avoid a break; and this fault was being repeated in India without the amount of consideration which he thought it ought to receive. He mentioned these facts in order to show that the 4 ft. $8\frac{1}{2}$ in. gauge was simply accidental, not arrived at on any scientific or good reason; and he believed that a medium gauge between the broad and narrow—

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say 5 ft. 3 in. or 5 ft. 6 in.—would be the most convenient for all countries, if it were possible to change to what was thought really best.

With regard to loose wheels, he agreed that they were certainly a great desideratum in the working of railways. It seemed to him that nothing could be more barbarous than to have a vehicle with two parallel axles, on which four wheels were keyed, so that they could not revolve independently and alter their relative speed in going round a curve. He understood from Mr. W. H. Barlow, the Engineer of the Midland Railway, that there had been a very large increase lately in the cost of the permanent way on that line, amounting to as much as 26 per cent. increase, while the cost of the locomotive department had not increased more than 10 per cent. during the same period. This was perhaps owing, he suggested, to the great weight of the vehicles and the difficulty of getting round the curves, especially in the case of engines with three axles and six wheels keyed fast upon them; the sharp curves at Trent junction were particularly difficult to pass through, and the carriages had to go sledging round, instead of the wheels being allowed to roll independently. He should therefore be very glad to see an invention which would allow of using loose wheels upon railway axles; and the inventor of such a method would be as much entitled to the gratitude of posterity as those who had invented the means of surmounting the narrowness of the 4 ft. 8½ in. gauge by making the carriage body project over the wheels.

Mr. Pole thought it would be quite out of place at the present time to attempt any comparison between Brunel and the Stephensons, to the advantage or disparagement of either one or the other. The Stephensons did not need praise; their monument was not the statue in Euston Square, but the prosperity of England at the present day, which was in so large a measure due to the labours of those two great men. The paper might be regarded partly as a chapter in the life of Brunel, because it certainly stated something which had not been generally known, and which had come to his own knowledge in a peculiar way, owing to the means of information that he had

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had as to the motives which led Brunel to introduce a wider gauge. But he had not intended to go into the respective merits of different gauges, except upon purely mechanical first principles; nor to renew any portion of the controversy which had taken place on that point, all of which might be found recorded in the voluminous reports published at the time.

The object of the paper had been, in the first place, to show how the present type of railway vehicle came to differ from the road type; and he had expressed the opinion that, on mechanical principles, the road type, with a broad base, a low centre of gravity, and large wheels, was a better type than small wheels, with an overhanging body, a narrow base, and a high centre of gravity. He had also attempted to show that Brunel was not actuated by a simple desire to make a big railway, but that he had a definite mechanical object in view, namely to restore the road type of vehicle, which was the reason why he adopted the great width of 7 ft. for the gauge. It was true that the old Eastern Counties line was laid with a 5 ft. gauge, and that there were proposals to widen the gauge on several narrow-gauge lines; but these were not founded on the same idea as Brunel's, who was not content with getting only a little more width, but intended to make such a complete alteration as would admit of restoring the road type of vehicle. This was the chapter in the life of Brunel which he had wanted to bring out in the paper, and he thought it did great credit to him; he had not found it mentioned previously, and if it were not founded on trustworthy evidence there might be a doubt about it; but it was on record, and the fact was indubitable.

With regard to the question of loose wheels, that was one point of superiority in the road type of vehicle which he thought would certainly have been returned to before now, if the broad gauge had been generally in use. It seemed impossible that with the broad gauge, and with the necessity for sharp curves, fixed wheels could have continued; they would have been intolerable; it was only the narrow gauge that had rendered them at all practicable.

So far from failing to appreciate the Stephensons, he thought that not only they, but subsequent engineers, who, in the face of that

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difficulty of the narrow space between the wheels, had brought railways to what they were now, were entitled to the greatest credit. The Stephensons succeeded in showing, as they intended to show, that the narrow gauge was capable of working the traffic of the country. Such items of information as those which had been mentioned with respect to the construction of the present powerful narrow-gauge locomotives did not show that the narrow gauge was better than the broad, but they showed the skill of engineers in adapting the present cramped gauge, and the unfavourable circumstances connected with it, to the requirements of the traffic of the country.

The PRESIDENT observed that to the list which had been given of different railway gauges might be added the Festiniog Railway, having a gauge of 1 ft. 11½ in., and the private line of 1 ft. 6 in. gauge at the Crewe Works; gauge therefore ranged from 7 ft. down to only 1 ft. 6 in., or 1 ft. 11½ in. on a public line. He remembered there was a railway company in America when he was there some twenty years ago which owned different lines and had three distinct gauges, so that they could not interchange their own rolling stock. The widths were 4 ft. 8½ in., 4 ft. 10 in., and 5 ft., all the lines being the property of one company; but shortly afterwards these discrepancies he believed had been reformed.

With regard to the relative stability of the present railway vehicles and those of the ordinary road type, it was represented in the paper that the common road vehicle with the body between the wheels was mechanically better than a vehicle which had the body overhanging the wheels, the base being proportionately wider in the first case, and the vehicle therefore safer. He was inclined to think however that a gauge of 4 ft. 8½ in. gave sufficient width of base, as far as the wheels were concerned; and that what had to be looked to, as far as stability of the body on the wheels was concerned, was the point where the body was supported on the springs. If Brunel's original idea had been carried out, and the body had been kept strictly within the wheels of a 7 ft. gauge, it would have involved internal instead of external bearings; the distance from centre to

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centre of the internal bearings on a 7 ft. gauge would have been about 6 ft. or 6 ft. 3 in., and that would therefore have been the distance between the centres of the springs, or between the points on which the oscillation of the carriage body took place. But with a 4 ft. $8\frac{1}{2}$ in. gauge and bearings outside the wheels, the distance between the centres of the journals was very much the same as between the inside bearings on a 7 ft. gauge. It appeared to him therefore that very nearly the same effect was obtained in regard to the stability of the body relatively to the wheels, by the use of outside bearings on a 4 ft. $8\frac{1}{2}$ in. gauge as by inside bearings on a 7 ft. gauge.

With respect to the question of loose wheels, he feared that the works in which he had himself at that time been an apprentice had had something to do with the discredit attaching to them. Some loose wheels had actually been made there for Brunel, intended for the Great Western Railway; but they were so badly designed by the maker and so defectively made, that they never did work, and never could have worked for any length of time, and they therefore brought discredit upon the whole system. If haply in those days the manufacture of the loose wheels, the value of which Brunel appreciated, had fallen into the hands of some one who would have spent more pains to make a good job of them, he could not help thinking that railways would not now be suffering from the disgrace, admitted by everyone, of having equal-sized wheels rigidly keyed upon parallel axles, which had to go round curves, and which ought therefore to be capable of having differential velocities.

He proposed a vote of thanks to Mr. Pole for his paper, which was not only interesting in itself as bringing forward the reasons, not hitherto explained, that had influenced Brunel in adopting the broad gauge; but it had also elicited a most interesting discussion, in which he would refer especially to the remarks of Mr. Armstrong, who was in the fortunate position of being able to speak with authority as to the working of both gauges, having under his charge on the Great Western Railway so large an extent of both the broad and the narrow gauge.

The vote of thanks was passed.

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The next paper "On Rock Boring by the Diamond Drill" having been read, the Meeting was then adjourned to the following day.

The Adjourned Meeting of the Members was held at the Institution of Civil Engineers, London, on Thursday, 29th April 1875; Frederick J. Bramwell, Esq., F.R.S., President, in the Chair.

The following paper, communicated through the President and read on the previous day, was discussed:—

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ON ROCK BORING BY THE DIAMOND DRILL, AND RECENT APPLICATIONS OF THE PROCESS.

By Major BEAUMONT, R.E., M.P., of London.

In this country important mechanical improvements are slowly accepted; but the principle being right, their progress is always sure. The subject of this paper has been discussed before in public, but the importance of the work done by the Diamond Drill is the reason for its being brought before this Institution. The writer proposes to dwell more particularly on the latest improvements that have been made in the applications of the diamond drill, and on the practical experience that has been obtained as to the best means of utilising the extraordinary properties of the black diamond, called carbonate in this country, and carbonado in Brazil, where it is found.

The diamond is the hardest known substance in nature, its comparison with the other materials next in hardness being described in Ure's Chemical Dictionary as

Diamond	20
Ruby or Corundum	17
Topaz	15
Quartz	10

The writer does not know by what process these figures were arrived at, but assumes that they are little more than guesses based upon the relative facilities with which the different materials can be scratched. Unless hardness means some quality which has no direct reference to durability under abrasion, he thinks that in these figures justice is not done to the diamond. If a well-chosen piece of black diamond or carbonate be brought into contact with solid quartz, the relative hardnesses according to the above table being only as 2 to 1, the quartz would have no chance at all; and the

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writer has seen specimens of quartz cut with comparative ease by a steel crown or boring tool set with diamonds, and running at a speed of about 300 rev. per min. He would quite expect a good crown tool to cut 30 ft. or 40 ft. run, before it was rendered useless; and it must be remembered that the diamonds in the crown tool can only be worn away about 1-32nd inch before it is rendered unfit to work, because any further wearing away of the steel in which the diamonds are set would involve the risk of their becoming loose in the setting.

To consider fairly the durability of the two materials, the work done should be looked at in the following manner. The amount of quartz ground up to an impalpable powder in boring 30 ft. depth would amount to 994 cub. in., which represents the contents of that depth of an annular ring $2\frac{1}{8}$ in. outside diameter and 1 in. inside diameter, 1 in. being the thickness of the core left untouched. The diamond consumed in doing this work would under ordinarily favourable circumstances be represented by a cube having sides of $\frac{1}{4}$ in., or 1-64th cub. in. Multiplying 994 by 64 gives 63,616 for the quantity of quartz ground up, as against 1 in the case of the diamond. The writer has also cut solid cores out of glass with a diamond tool. There was necessarily only a small thickness of glass to operate upon, about 2 in., but it could not be seen that any effect was produced on the diamonds; and it appeared quite practicable to drill a deep hole in a material like glass, in which, in consequence of its being homogeneous and having no cracks or flaws, hardness was the only difficulty the diamond drill would have to overcome.

It has frequently been suggested to try to shape the diamond to a cutting edge; but according to the writer's view such suggestions are made under a misconception as to the action of the diamond, which does its work by absolute main force. It is a question not of cutting, but of abrasion, the harder material wearing down the softer one; and any attempt to shape the diamond to a cutting edge would reduce the area subjected to abrasion, and place the diamond in a worse position for doing its work, until its sharp edge had been worn off, which would very soon be the case. This

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remark is only intended to apply to the diamond as used for drilling hard rocks. For soft rocks a cutting edge would stand; but such a material would be so easily cut that there would be no advantage in putting the cutting edge on the diamonds.

It appears to be one of the most extraordinary facts in nature that there exists this enormous difference in hardness between the diamond, so completely infinitesimal in bulk, and all other materials. Carbonate is found in connection with the diamond proper, or valuable gem, in the mines of Brazil. It has not as yet been discovered in the diamond diggings of Africa; why, the writer cannot say. The chemical composition of carbonate and of valuable diamond is stated to be the same, only that the gem is crystallised, while the carbonate is uncrystallised. The writer apprehends it is the fact of its having no stratification which makes the carbonate so valuable for commercial purposes, a bright diamond being more brittle or likely to split; hence, apart from their relative values, for the present purpose the less valuable material is the best. The first carbonate was introduced into Europe as a speculation, and was offered to the diamond cutters at Amsterdam as a material equal in hardness to the diamond dust they were using, and of only a nominal value. Such however was the effect of prejudice, that it was rejected, and at first a hatful of carbonate might have been purchased at 4*d*. per carat; but now, depending on its quality, it is worth from 15*s*. to 25*s*. per carat.

In boring into rocks, the hardest known steel is of no use except percussion is used, because, if it is attempted to give a cutting or rubbing action to a steel tool, it is impossible to construct it so that it can work for more than a comparatively short time. Mechanics having only steel at their disposal have been driven therefore to employ percussion in designing machinery for making holes in rocks. It is well known how comparatively difficult it is to give a definite percussive motion and to control it; and how, unless an altogether disproportionate amount of strength be given to the parts, it is impossible to construct a machine to do a great amount of work in striking blows, and yet to be durable. Moreover the work done by the hammer, and its source of power, ought not to be far

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apart; or in other words, a series of blows represents work done in a shape in which it is very difficult to transmit it to a distance.

The use of the diamond in this case breaks, as it were, the bottom of Columbus' egg, and many of the difficulties attending machinery for dealing with rocks vanish at once. As an illustration, what a wonderful improvement would be the use of an auger in boring holes in wood, if the only means of drilling that material were hammering a nail in and pulling it out again, or cutting a hole with a gouge and mallet.

The application of the diamond to Mining purposes may be described as the power of making holes in the hardest substance, rapidly, continuously, and without striking blows. For shallow holes, such as those required for ordinary quarry work, shaft sinking, or tunnel driving, the relative advantage of the diamond drill is not so great as it is where holes of a greater depth are required; and the greater the depth, the greater is the advantage of the system: inasmuch as, while difficulties accumulate rapidly with the depth of a hole made by percussion, with the diamond drill they remain the same, and an almost unlimited depth could be drilled without withdrawing the tool, which in the case of deep prospecting holes is a very lengthy operation.

The diamonds are set in a steel crown, as shown in Figs. 18 and 19, Plate 16, and in the specimen exhibited. The crown is kept supplied with water, and is rotated at from 200 to 300 rev. per min., under a pressure varying with the nature of the rock from 300 to 800 lb. Under these circumstances the writer has seen the hard Pennant rock of South Wales cut at the rate of 6 in. per min., a 3 ft. 6 in. hole being put down in 7 min. and a 2 ft. 6 in. in 5 min., and this not as an exhibition, but at the bottom of a shaft in course of construction.

Various ways naturally suggest themselves for putting the requisite amount of pressure upon the crown. In Fig. 12, Plate 15, is shown the way in which this has been done up to the present time in the case of drills for tunnel driving and shaft sinking.

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A screwed tube A, carrying the crown, is driven round by one wheel B, and forced forward by a screw C driven by another wheel D, the two wheels B and D being differential, and set in motion from the same shaft S driven from the motor. A friction clutch F is arranged so that when the pressure required to make the drill advance exceeds a certain amount the feed relieves itself. When in good order this arrangement answered very well, but in the rough hands of the miners, and in the wet and dirt of a tunnel, the men would screw the friction gear down directly the drill was not working properly, irrespective of the cause; and as soon as they got a satisfactory cut, no matter what the pressure might thus be, nothing would be touched, and no thought given to the time the diamonds were having of it. An arrangement has therefore been devised by Mr. Gulland, the Diamond Rock Boring Company's engineer, in which the pressure necessary is put on by a piston in a cylinder acted on by compressed air, as shown at P in Fig. 5, Plate 11, thus taking it out of the power of the workmen to exceed a given amount.

The diamond drill is applied to three distinct classes of work, namely :—

1st.—Prospecting or putting down exploring holes for the purpose of testing ground.

2nd.—Tunnel driving, and Shaft sinking.

3rd.—Subaqueous operations.

Prospecting.—The first Prospecting machine was made by Messrs. Appleby of London; and in Figs. 1 and 2, Plates 8 and 9, is shown the largest form of prospecting machine, as made by Messrs. Ormerod Grierson and Co. of Manchester, who are now constructing the prospecting machinery for the company. The principle of the two is the same, but the latter machine is far more powerful than the former one, and is capable of dealing with the heavy boring bars and large crowns required to cut cores of 3 to 6 in. diam. and several feet length, such as those of which portions are exhibited. The lifting gear for taking the boring rods out of the hole is also more powerful, and an arrangement has

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been made by which the quill and turning gear can be lifted clear of the line of the hole, and so allow the boring rods to be more readily manipulated.

The prospecting machine consists of two vertical girders, Figs. 1 and 2, carrying between them a hollow quill A made of sufficient size to grasp and turn the boring bars. This quill has a rotating motion given to it by means of an inclined shaft S driven through bevel gear, power being transmitted by means of a belt B from the flywheel of a portable engine. The pressure necessary to cut the rock, as previously described, is given by the weight of the rods, reduced where necessary by counterbalance weights W. For holes of a moderate depth, say up to 1200 ft. or 1300 ft., an 11 in. cylinder engine with 40 lb. steam pressure is sufficient.

The boring rods, shown in Figs. 13 and 14, Plate 16, are withdrawn whenever it is desired to know the nature of the strata being passed through; and as the rods are not so large as the hole, a core tube has to be used at the bottom of them, to receive the core cut, as shown in Fig. 15, and the length of this tube limits the boring that can be done at one operation. In practice the core tube is about 10 ft. long. The diamonds are kept cool, and the debris continuously removed, by a stream of water pumped down through the hollow boring bars, which after passing under the crown rises up to the surface through the space between the rods and the sides of the hole.

The writer does not think he is taking an unpardonably favourable view of this system, in saying that for prospecting purposes it is distancing any other known appliances, especially in the two important particulars of speed and of the evidence afforded respecting the ground passed through. On the latter point the samples before the meeting will speak for themselves; and Mr. Willett, the secretary of the Sub-Wealden exploration in Sussex, in his report of 31st March last, writes as follows:—"Now we are extracting continuous columns, from 7 to 8 ft. high, of hard stone,—accurate sections of deposits 300 ft. beneath us. The discoveries made during the past quarter are confined principally to correcting

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erroneous observations and deductions in passing through the same ground (312 ft.) through which we toiled so slowly for twelve months under the old system. Whereas under the old system of chopping and smashing, by alternately lifting and dropping a heavy chisel, the sides of the bore were necessarily abraded by repeated friction and percussion, it followed, as a matter of course, that the mud auger used in clearing the debris from the bottom frequently brought up thence fragments of rock which had fallen from and belonged to a much higher level. These fragments were naturally supposed to represent the strata existing at the bottom, and consequently inaccurately represented existing facts. Our new continuous cores portray laminæ of deposit as numerous as twenty to the inch; indeed it is impossible accurately to delineate, if it were desirable, the sudden and minute variations in the nature of the strata passed through."

In some cases of course the strata may be so soft that they will not stand cutting by the diamond drill; but in that case an ordinary tool may be used, and the evidence given by the washings which are brought up from the water circulating in the hole is even then more satisfactory than the ordinary system of boring can furnish.

With reference to speed, this varies very much, as indeed might be expected, when the hazardous nature of boring operations is considered. The delays do not occur from the difficulty of cutting, but from accidents, the effect of which is to delay the work by jamming the boring rods or core tube in the hole. Under ordinary circumstances the breaking of the rods is thought nothing of, as tackle is provided which readily recovers them; but sometimes they get so jammed as to make it impossible to get them out without over-boring, that is, sending down a tool which is larger than the one lost, and which passing over releases and brings it up.

As evidence of rapid boring, a bore-hole at Böhmisch Brod in Bohemia was commenced on 15th July 1874, and finished $3\frac{1}{8}$ in. diameter to a depth of 2300 ft. in 130 days. At a bore-hole at Hamm in Westphalia, 500 ft. of boring, completing a hole $2\frac{3}{8}$ in. diameter from 1500 ft. down to 2000 ft., was done in the

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extraordinarily short time of 17 days, and good cores were obtained at that depth. It has to be noticed that this 500 ft. was commenced at no less a distance from the surface than 1500 ft. No doubt the strata were most favourable, but when the enormous depth at which this portion of the work was commenced is considered, it will be allowed that the performance resembles more the fiction of fairyland than reality, and had the writer prognosticated such a result as possible a few years ago, it would have been looked upon by most practical men as only the wild dreaming of an inventor.

A bore-hole at Widdrington in Northumberland was commenced on 9th February, and completed to a depth of 1565 ft. in 265 days; and a bore-hole for Messrs. Bell Brothers, near Middlesbrough, was completed to a depth of 1355 ft. in 210 working days of 9 hours each, including all stoppages in both cases. The latter bore-hole passed through a bed of solid salt more than 100 ft. thick, a sample of which is on the table, and when the salt was reached the water dissolved it, preventing the formation of a core; consequently before obtaining solid evidence it was necessary to circulate completely saturated brine instead of water.

In the case of the Sub-Wealden boring, the first hole was lost at a depth of 1034 ft., principally owing to difficulties belonging to the continuation of a hole commenced by another system, which for the first 300 ft. was 9 in. diameter. The second hole was commenced on 11th February, and this is now over 750 ft. deep, and during the last week 125 ft. depth has been done. Provided the exploration committee obtain sufficient funds to enable 2000 ft. to be reached, the writer has little doubt that the work will be completed to that depth well within the present year; and can be continued to any further distance, down to 3000 or even 4000 ft., that may be thought necessary for completing this extremely interesting scientific investigation. It is of great importance to mining engineers to know the nature of the ground that they have to pass through in sinking pits; and in order to ensure the pits being put down in the best position for advantageously developing a mineral field, the existence of faults, any throws up or down, and the lay and

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inclination of the strata ought to be thoroughly known. With the old system the time employed in boring, and the meagre information afforded, made it impossible for a proprietor to forewarn himself; but with the diamond drill these difficulties vanish to a great extent, and the writer believes the time is come when no shafts will be sunk without a preliminary investigation of the field by boring.

Tunnel Driving.—The diamond boring machinery as adapted to Tunnel Driving is shown in Figs. 3 and 4, Plates 10 and 11. It consists of a couple of standards carrying drills, constructed as previously described, which are all set in motion by one engine driven by compressed air. This system has given excellent results, but its defects are that an accident to a portion of the machinery affects the whole, and the number of driving shafts and wheels necessarily employed, owing to the frequent changes of direction of the power, makes it a very expensive machine to keep in repair, especially as the limited space does not admit of the desirable size and strength being given to the wheels. For example, the whole power of the engine, which with a 12 in. cylinder and 35 lb. air pressure, working at a piston speed of 300 ft. per min. and cutting off at half stroke, amounts to nearly 30 H. P. actual, has to pass through a pair of bevel wheels only 9 in. diameter. The object aimed at in this arrangement was to ensure a sufficient amount of power to prevent the work of drilling from being stopped if a drill were accidentally to stick.

A very satisfactory result has however been obtained with a drill driven by a pair of $4\frac{1}{2}$ in. oscillating cylinders attached direct to it. These are capable of bringing as much force to bear on the drill as it is fit to receive; and that being the case, this arrangement has the great advantage of the work being at once stopped whenever the strain exceeds a proper amount. The adaptation of this principle to a tunnel-driving machine is shown in Fig. 5, Plate 11. It is anticipated that such an arrangement will take the place of the previous machinery driven by gearing. A rotary engine is proposed to be employed, in which a number of plunger

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pistons act on the periphery of an inclined disc, giving to it the motion of the old disc-engine, while the action of the pistons in the cylinders in no way differs from that of those ordinarily in use. The pressure is put on the boring tool by means of a piston P in a cylinder acted on by the compressed air; and the drills are supported on the standards in such a manner that they can put a bore-hole in any position that the miner requires.

Shaft Sinking.—In Figs. 6 and 7, Plate 12, is shown the Shaft Sinking machinery which is at the Quaker's Yard Pits of the Harris' Navigation Coal Company in South Wales, where it was seen at work by the Members on the occasion of the Cardiff Meeting of the Institution last summer. In principle it is the same as the tunnel-driving machinery shown in Figs. 3 and 4, the drills being carried on a frame suited to the altered circumstances of the case, and driven by a pair of short-stroke 12 in. trunk engines.

The previous criticisms on the old form of tunnel-driving machinery apply in this case, and in Fig. 8 is shown the new form of drill which will be applied on girders attached to the suction pipe of the pump, the drills being either lifted out of the pit at the time of firing a charge, or hung a certain distance up the side so as to be out of the way of the shots. The girders are made to joint together, thus suiting themselves to whatever position in the pit they may be required to be placed in; and they will never leave the bottom, as the shots will not harm them.

It has been proposed, and is stated to have been carried out in America, to sink shafts by drilling a number of deep holes, say up to 500 ft. depth, all parallel and in line with the shaft. The drilling operations being completed, the holes are filled up with sand or water and blasting is commenced, a portion of the bore being scooped out each time, and the blasting continued until the whole depth bored has been excavated. The writer has tried this system, but without a satisfactory result, having found that the straight holes answer very well where there is a free side to blow to; but without this, no amount of explosive will make them work properly.

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In a wet pit, such as that at Quaker's Yard, which is the most difficult case a miner can have to deal with, the progress depends upon the speed at which the sump receiving the suction-pipe of the pump is carried down. To ensure a good sump, inclined blast-holes with a good lift are a necessity. It will be noticed that the arrangement shown in Fig. 8 lends itself especially to putting down these inclined sumping holes. It is proposed that the cropping or outside holes, and all those necessary to get the body of the shaft away, should be put down as deep holes, varying in depth say from 20 ft. to 100 ft. as might be found convenient. The drills having completed this work would be removed from the shaft, leaving only say one or two, which would be necessary to put down the sumping holes from time to time required, and also to increase the number of the deep holes, should the shaft accidentally get fast. This contingency might be avoided by boring a sufficient number of deep holes at first; but such a course would involve the objection of doing an amount of boring which in many cases might be unnecessary.

The circumstances that obtain in applying machinery to a tunnel are different from those in a shaft, inasmuch as in a heading it is impossible for the operations of boring and of removing the rubbish to go on at the same time. The work in driving headings divides itself into two operations:—first, the drilling of all the holes necessary to bring the face away; and secondly, the blasting of the holes so bored, and the removal of the rubbish. In the case of a shaft, the area is so large that machinery cannot conveniently deal with the whole face at once; nor is it desirable that it should do so, as it is found conducive to progress that the boring and the removal of the rubbish should be carried on simultaneously. Again, the face on which the machinery has to work being horizontal in the case of the shaft, but vertical in that of the tunnel, it is an absolute necessity in the latter case that the holes should be bored and the blasting done in such a way as to leave a square face for the machine to start work on when brought forward again; but in the case of the shaft,

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machinery can be used, no matter how irregular or in what condition the bottom may be.

In connection with this, the writer may point out what in his judgment is an error that is often fallen into in criticising the operation of drills in heading-driving. It is thought that the machinery is not doing its work properly unless it can put in the holes in the same position that miners put them in, and that it is a fault if the machinery necessitates a greater amount of holing. But an amount of holing which it would be very difficult for men to do affects the machine but little, and whether 15 holes or 25 have to be put in to get away a length of forehead is not of very great importance when the machinery is once fixed, and is of adequate power. And again, whether somewhat more or less dynamite or other explosive is used, has little significance when it is considered in relation to the great advantage offered by the machine in the increase of speed. If it is considered that the machinery is going to give an advance in speed of only 20 or 30 per cent. over hand labour, these two points have a serious significance; but when the advance is 200 or 300 per cent. over hand labour, the extra cost is more than balanced by the value of the increased speed.

In tunnel driving, where, for the reasons above stated, only short or moderately short holes can be used, the diamond drill is in direct competition with percussive drills, and it is only a question of economical working. The matter however is widely different in shaft sinking, where the deep holes can in the writer's opinion be most profitably employed; and for this purpose he believes that the diamond drill will be found to have no rival, and that it will enable shafts, especially in hard and wet ground, to be put down in from one-half to one-third of the time in which they can be completed by hand labour, and also at a less cost.

A novel application of the diamond drill has been successfully made in one or two cases, where it was desirable to drain the water from a pit in course of being sunk to workings at a lower level. This was done at the Risca Colliery in South Wales, by putting down in 11 days a 4 in. bore-hole 211 ft. deep, which effectually drained

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the shaft and allowed the sinkers to work dry; the bore-hole was kept open by a piece of wire rope, to prevent its becoming choked by debris.

Subaqueous operations.—The last class of operation to which the diamond drill has been applied is putting down blast holes under water, for the purpose of removing rocks. This is an application to which it is peculiarly adapted, as the circumstance of the holes being under water makes no difference in its working, and the working is not affected by the distance of the crown from the source of power; consequently it is no matter what the depth of the water may be under which the drill has to work.

In Figs. 10 and 11, Plate 14, is shown the Subaqueous Boring machinery as it is at the present time at work, removing over 200,000 tons of rock in the River Tees, at the 8th Buoy Scarp, under contract with the Tees Commissioners. The machinery consists of drills D D, as before described, arranged in four rows and driven by four sets of shafting S S running lengthways along a barge, the whole being set in motion by a pair of 12 in. cylinder horizontal engines E. The barge is supported on eight legs L L, and tackle is provided by which these legs can be raised or lowered to suit the inequalities of the bottom.

The operation consists in taking the barge to the rock at quarter to half ebb tide, lowering the legs to the bottom, and locking the barge to them; then as the water falls the barge remains suspended upon the legs, and affords a stable platform to commence drilling from. This operation is begun by jamming a wrought-iron tube under each drill between the rock and the barge. The drills are then set to work, their rods passing down inside these tubes; the holes are drilled to the requisite depth, and the drills withdrawn and slid clear of the holes. Dynamite cartridges are then introduced through the tubes into the holes, the last cartridge in each hole having in it an Abel's fuze which fires a detonator, the fuze being attached to insulated wires. No tamping is required beyond occasionally a little sand poured down the tube to prevent the run of the tide, which is very strong, from pulling the wires out.

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The tubes are then withdrawn, the wires passed from out of them and brought together upon the deck of the barge. The tide has in the meanwhile risen, and as soon as the water takes the weight of the barge, the legs are drawn up, the mooring chains hauled on, and the barge drawn some 50 ft. clear of the site of operations. A Siemens battery is then brought into successive connection with each wire, and the charge is fired.

This completes the operation, which is recommenced in a new place the next day. The holes are 10 ft. apart from centre to centre, the charges used are $\frac{3}{4}$ to $1\frac{1}{2}$ lb. of No. 1 dynamite, and the rock is completely broken up by the blast, as shown by the following extract from the certificate of Mr. Fowler, the engineer to the Conservancy Commissioners:—"The blasting operations by the Diamond Rock Boring Company, under contract with the Tees Commissioners, are being carried out to my entire satisfaction. The rock appears to be thoroughly broken up by the shots, and the dredger is lifting the broken rock to the full contract depth at the rate of 1100 tons per day. So far as my judgment goes, boring is a necessity, and it would have been impossible to produce such results by laying the charges on the surface."

The whole of this operation from beginning to end is performed without the use of a diver, and in point of fact, since the work began, the writer is the only person who has been to the bottom of the Tees, he having gone down to see how the rock was broken up by the shots. The rock is a softish sandstone, running in bands.

The writer believes that the use of the diamond drill will open quite a new field for operations of this description, and that subaqueous obstructions, which are unfortunately too commonly in the way of the entrance to ports and harbours, can by this means be removed very readily, and at a moderate cost.

As with the other classes of boring machinery described, the means are now found of very materially simplifying and improving the arrangements. In Fig. 9, Plate 13, is shown the machinery that will in future be employed for subaqueous operations. It enables the barge to be kept floating, and thus makes available

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any ordinary barge, and does away with the difficulty of suspending a heavy weight like 100 tons on legs in the air. The drill enabling this to be done differs from those hitherto described, in this particular, that its engine stands on the drill and itself gives the weight necessary to cut the rock. The engine E slides on the vertical girder G which is attached to the barge, and consequently the barge can have a vertical motion without interfering with the working of the drill D. To prevent any lateral or horizontal motion, which would break the drills in the holes, four legs L L will be used, of sufficient weight to hold themselves on the rock, and the barge will slide up and down them as the tide rises or falls. The legs will be lifted when the barge is required to be moved, as at present; but the tackle for doing this will only be required to deal with the weight of the legs and not with that of the barge.

Before the present expensive machinery was constructed, it was considered desirable to see whether the anticipations formed of the diamond drill for this particular purpose would be justified in practice; and further, what distance apart the holes would require to be in order to break up the rock sufficiently. For this purpose a single pile was constructed, as shown in Fig. 12, Plate 15, sufficiently strong to support a single drill, with the platform for working it; and it was moored by guy ropes so as to hold it steadily in a vertical position. This arrangement permitted the drill to work satisfactorily, and the required evidence was obtained; but the operation was necessarily so slow that in smooth water and where a barge could be employed it was of no use. But in rough weather the writer believes this system to be the only one which is capable of dealing in a practical way with the difficulties attending the putting down of large bore-holes in deep water.

Such an arrangement would meet the circumstances which obtain at Daunt's Rock off Cork Harbour. This obstruction consists of a plateau of rock, having three prominent summits, and embracing a considerable area, shelving gradually into deeper water towards the mainland, and having an abrupt face towards the sea. In the whole year there are probably not more

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than twenty absolutely calm days on the rock, and ordinary summer weather would be so rough as to make it impossible to use such a barge as has been described. Not so however in the case of a pile; and the general features of the proposals which have been made on behalf of the Diamond Rock Boring Company to the War Office, who are charged with reporting upon the removal of the rock, are as follows:—To use a hollow pile dropped into the required position by shear-legs from a steamer, and held by fixed guy ropes from moorings laid down so as to command as large an area of the rock as possible; the drill being worked from a staging on the top of the pile, and driven by a pair of cylinders supplied with steam conveyed through a flexible pipe from the attendant steamer's boiler. When the hole is down, the explosive would be introduced through the pile, together with the electric wire for firing, the pile being then removed to another place. A hole 24 ft. deep could be put down and fired in 24 hours, and if its diameter were 6 in., it would hold about 5 cub. ft. of dynamite, an amount which under the circumstances could not fail to produce an enormous effect.

The object of using large and deep holes in preference to small and shallow ones is to reduce as far as possible the difficulties that attend the establishment of a stable platform on which to work in cases where rough water is to be contended with. Were it not for this consideration, the best arrangement for reducing the rock to the small size necessary for removal would be to use small charges in holes a moderate distance apart—the system indeed which is employed on the Tees. The smaller number of heavy charges fired with large and deep holes would result in a portion of the rock being blown into large lumps; once shifted however from their bed, these could be readily broken up, and that possibly without the use of holes. No reasonable amount of explosive fired on the surface of the solid rock while still bound in its bed would produce a satisfactory result. In practice, vertical holes are found to answer well; and this might be expected, when it is considered that the weight of water on the top of the rock practically renders all the lines of resistance equal.

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Major Beaumont exhibited a diagram of the strata passed through in the bore-hole put down for the Sub-Wealden exploration in Sussex, as ascertained from the succession of continuous solid cores brought up by the drill, which had supplied the means of correcting the geological discrepancies in the former diagram that had been prepared from the previous boring attempted at the same place. He showed a number of samples of cores, from 3 to 6 in. diameter, obtained from this and various other bore-holes; and also specimens of the crown drills set with the diamonds, both new and worn down so far as to be ready for re-setting.

In reference to the proposed subaqueous employment of the diamond drill for the removal of Daunt's Rock, he remarked that this was an entirely new application of the drill, and one which he thought was likely to get over difficulties that had been found under similar circumstances to be almost insuperable. The advantage which the diamond drill had to offer for that purpose consisted in its being able to put down a hole of such large size as would admit of firing under water a charge of as much as 4 or 5 cub. ft. of dynamite. The machinery necessary for putting the holes down had been simplified, and the operation was simplified also, inasmuch as it was thus only necessary to fire a single hole, instead of a large number of holes as would have been the case under other circumstances. As to what the result of the explosion would be, no doubt it would produce a very considerable effect upon the rock; but instead of blowing it into a number of small pieces, it would break it into pieces of considerable size. As to whether or not these large pieces would be difficult to break up afterwards for removal, the experience he had had was, that although it would be a useless expenditure of dynamite to fire a charge upon the surface of a rock which was even, and was not relieved by any cracks or fissures, but was bound in its bed, yet the reverse was the case if the rock was loose; and consequently the blasting of a rock like Daunt's Rock into large masses would not really be any disadvantage, because these could readily be broken up afterwards into smaller pieces by surface charges of dynamite, without requiring any more holes boring in them for the purpose.

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A further advantage in this method of dealing with the rock was based on the consideration that it would be extremely difficult to establish a platform upon a rock situated as Daunt's Rock was, some three or four miles out at sea, exposed to the heavy gales and seas that obtained in the Atlantic ocean on the Irish coast; and practically he considered it would be almost an impossibility to fix any kind of platform there with such stability as would allow of the boring operations being carried on for a week or a fortnight together. He did not think the difficulty would be met by putting upon the rock a platform which might be swept away in a week or ten days, because it would need many repetitions of this work, which would involve such an amount of cost as to make it impracticable. The principle that he had proposed for the removal of the rock was to take a single pile, and drop it upon the rock from sheer legs on a vessel, and then hold it steady in position by guys fastened to anchors on the rock, the anchors being arranged so as to cover as large an area as possible. A pile so anchored might be expected to stand against any ordinary bad weather; or if it were washed away, it would be no very serious matter to replace it. Unless some plan of that kind were adopted, it would be found extremely difficult to obtain a stable platform sufficiently permanent for enabling the work to be carried on continuously. These were the practical points upon which he should be glad to hear any suggestions, feeling greatly interested in the success of the work, because he believed the removal of Daunt's Rock to be a matter of almost national importance.

Mr. S. C. Homersham mentioned that during the last five-and-twenty years he had had to put down a good many bore-holes, some small and some large, some by hand and some by steam power; and one of the latter had been sunk in 1863 to a depth of 1312 ft. at Middlesbrough for Messrs. Bolckow and Vaughan, in the same strata as the hole of 1355 ft. depth described in the paper, and passing through the same thick bed of rock salt. The hole was 18 in. diameter, and was sunk from the bottom of a well 180 ft. deep to a total depth of 1312 ft. below the surface, or 1132 ft.

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below the bottom of the well, an iron pipe being brought up from the bottom of the well to near the surface, through which an 18 in. bore head could go. The machine used was one of Messrs. Mather and Platt's percussive steam boring machines, and the time occupied was 254 days, including Sundays, or 218 working days of about 11 hours each, including all stoppages. The rate of sinking was therefore 4 ft. 5 in. per day, including Sundays, or 5 ft. $2\frac{1}{4}$ in. per working day of 11 hours, which was equal to $5\frac{5}{8}$ in. per hour. In the same strata it appeared from the paper that the diamond drill had bored 1355 ft. in 210 working days of 9 hours each, or at the rate of 6 ft. $5\frac{3}{8}$ in. per working day of 9 hours. This was equal to $8\frac{5}{8}$ in. per hour, showing a clear gain of 3 in. per hour by the use of the diamond drill in that case as compared with the percussive machine which he had employed, the latter being in his opinion one of the best kinds of percussive boring machines that could be used. The greatest depth bored by the percussive machine in the day of 11 hours was about 12 ft., and the least depth in the same time about 12 in., the depth varying with the hardness of the strata met with, and not exactly with the distance from the surface, because sometimes in the middle of the depth as great a rate was attained as at the commencement of the boring. He should be glad to know what was the diameter of the bore-hole sunk by the diamond drill at Middlesbrough, and what had been the cost of sinking it. The hole that he had sunk with the percussive machine was 18 in. diameter, and he did not think a smaller hole could have been put down any more quickly by that machine, because a strong rope was required to work the boring tools, which were of large size and weighed from 1 to 2 tons, and required consequently a sufficiently large hole to work in advantageously; so that if a 12 in. hole had been tried, he thought it would not have been carried down faster than the 18 in. hole, and probably not so fast. The total cost of sinking the 18 in. hole to the depth of 1132 ft. had been about £1200, the machine and tools being hired at £5 per week, while the coals, wages, cutters of special tools, and repairs formed an additional charge; and if some information could be given as to the cost of boring with the diamond drill, it would be valuable. Certainly

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in some of the deep borings the speed attained with the diamond drill far exceeded anything that he had seen previously, being fully 50 per cent. more in the boring at Middlesbrough than the speed attained with the percussive machine.

Mr. C. Cochrane drew attention to the attempt which had been made to put down a bore-hole by means of the diamond drill in the Cannock Chase coalfield, where he understood considerable difficulties had been met with in going through what was called the pebble bed, which had proved a grave obstruction to the passage of the diamond drill. He enquired in what way it was expected that the difficulties presented by the occurrence of the pebbles in this and similar instances could be overcome.

Mr. J. N. Shoolbred mentioned that he had recently seen McKean's percussive drill employed in the formation of the Severn Tunnel; and as it appeared the diamond drill had been applied to tunnel driving, he should be glad if some idea could be given as to what had been the results obtained with it under similar circumstances. The portion of the Severn Tunnel now in course of construction by the Great Western Railway across the broad portion of the Severn, in order to shorten the route from London to South Wales, had been thus far driven through the hard strata immediately below the coal measures, consisting of carboniferous limestone, millstone grit, firestone, &c.; and he understood that the rate of progress made there with the percussive drill was considered very satisfactory. The holes bored were about 1¼ in. diameter and from 2 ft. 6 in. to 3 ft. deep; and ten or twelve of these were required in the face of the heading, which was 7 ft. square, to prepare for a blast, the time taken in drilling them being on an average from an hour to an hour and a half. The progress made up to the present time with two machines had been at the rate of from 12 to 19 yards per week. In hard strata, such as those beneath the Severn, he understood the diamond drill was peculiarly fitted to work; and if there had been any parallel work executed by that drill, it would be interesting to be able to compare the rates of progress obtained by the two machines.

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Mr. E. A. Cowper considered the paper now read was a very valuable one; and the idea of sending down a saturated solution of salt, when the drill was passing through a bed of rock salt, was certainly a most ingenious way of meeting the difficulty that would otherwise arise from the rock salt becoming dissolved out. For in a salt bed of such a thickness as 100 ft., if a large hole were dissolved out round the boring tube, there would be no guide for the tube after it had got past that place. But supposing the strata were of the nature of soft clay, loose gravel, loose sand, or other soft material that would wash away more or less with water, he should be glad to know whether there were any means of meeting the difficulty of the boring tube being very loose for a considerable depth at such a place; there might probably be some means of obviating the inconvenience, either by lining the bore-hole with tubes at that part, or by some other plan of that kind. Also if some information could be given, from the experience obtained with the diamond drill, as to the progress made in driving tunnels when blasting with dynamite or gunpowder, it would be instructive to all engaged in such operations.

Mr. C. W. Siemens observed that, as it appeared that the carbonate or black diamonds in the rock drill did not cut with a sharp edge, and that it was useless to shape them in any way except perhaps in boring very soft material, their action was evidently reduced to one of absolute crushing and grinding; and he should be glad to know what was the pressure put upon the diamond per square inch, in order to produce such an action on a hard rock. If the pressure put upon the diamond were a moderate one, he apprehended it would simply produce a smooth polished surface on the rock which it was intended to rub away; and he supposed the pressure must be such as really to crush the rock under the diamond. That must be a very considerable pressure,—a pressure of several tons per square inch; and he enquired whether it did not come up nearly to the crushing point of the black diamond itself.

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Mr. J. T. Thorneycroft—referring to the passage of the drill through strata containing pebble beds or loose stones, and to the statement made in the paper that the tool had occasionally got jammed, so that it had to be drilled out—enquired whether in such cases a lining tube was inserted through the loose ground, so as to protect the tool from being similarly jammed again. He asked also whether very soft beds, such as had been alluded to, were found at any great depth, or simply in the higher strata; and whether in the latter case the difficulty presented by their occurrence could not be overcome by inserting a tube in the bore-hole for a certain distance down; below a certain depth he imagined solid rocks would generally be found. The diamond drill certainly appeared to give the means of obtaining very accurate sections of the rocks passed through, besides which it had the advantage over other methods of great rapidity.

Mr. R. H. Tweddell enquired in what manner the core was brought up by the diamond drill after the hole had been bored. With regard to the pressure put upon the diamonds to produce abrasion in boring, it had been stated in the paper that a pressure of from 300 to 800 lb. was required, according to the nature of the rock; that was however the total pressure upon the drill or upon the area of the hole bored, and not the pressure per square inch upon the diamonds. He asked also in what proportion the cost of the boring increased according to the depth.

Major Beaumont, in reply to the various enquiries which had been made, said he had no doubt the strata met with in the bore-hole put down at Middlesbrough by the percussive machine were analogous to those which had been passed through in the same locality by the bore-hole of 3 in. diameter put down by the diamond drill. The boring executed there by the percussive machine was a very remarkable one, and he was glad to know what the actual cost of that work had been, having always heard its cost spoken of as considerably above what had been mentioned; in which impression he had been confirmed by the fact that Mr. Bolckow had since

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expressed his regret that the diamond drill had not been available at the time the work was commenced.

Mr. S. C. HOMERSHAM said it must be borne in mind that in the case of that bore-hole there had been already a well sunk 180 ft. deep, which was lined with cast-iron cylinders the whole way down; this had of course been a great expense, and it was not included in the cost that he had stated, which was merely the cost of the bore-hole put down from the bottom of the well.

Major BEAUMONT considered the cost of about £1 per foot for putting down that bore-hole to the depth of 1100 ft. was a very remarkable and satisfactory result indeed; and he apprehended it was analogous to some of the examples referred to in the paper, in being an exceptionally good result, as he had never known an instance of a bore-hole being put down by the percussive method to such a depth at anything like the moderate cost now mentioned. As a matter of fact, in two cases at least, borings which had been commenced by the percussive drill, and had been obliged to be abandoned, had been handed over to the diamond drill. One of these was in Nottinghamshire, and was already completed; and the other, now in progress, was at Messrs. Meux's brewery in London. In the latter case a bore-hole had been put down to a depth of 800 or 900 ft. by the percussive drill, and then difficulties had been met with by the cutter getting jammed in the bottom of the hole; and an attempt had been made to fill the hole up again to a certain height from the bottom with cement and bricks, with a view of getting a solid foundation to recommence the boring in, so as to cut a fresh hole through this artificial bottom. That however did not succeed, and it ended in the matter being in this position, that a large sum had been expended on the boring, and the depth of the hole at the last was a little less than it had been some time previously, besides which one of the large percussive cutters, weighing about half a ton, was left jammed in the bottom. As in the instance of the boring referred to at Middlesbrough, he believed the percussive machine had been hired from the makers,

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who could not therefore be considered responsible for what had been done in working it. By means of the diamond drill the bore-hole had now been cleared out, down close to where the cutter was stuck fast, where he expected it would be found to have dropped into a cavity on one side; or if not, he thought some other way could be found by which the difficulty could be got over, and the lining tubes got past this obstruction.

The remarkable result attained with the percussive drill at Middlesbrough, in boring 1100 ft. depth at £1 per foot, was one which the diamond drill was not likely to emulate in point of cost. The question of cost was indeed one more of commercial than of scientific interest, and the company owning the diamond drill had arranged a scale of prices at which they were prepared to work; it was considered that the advantages offered by the diamond drill in point of speed, and especially in the evidence which it was able to afford as to the nature of the ground bored through, would compare satisfactorily even at an increased cost with the results obtained by means of other drills. It would readily be seen that there was scarcely any more hazardous work than boring, in respect of the cost incurred. Provided everything went well, the boring could be done at one fourth or even one sixth of the regular cost at present charged; but in practice how seldom it was that everything did go well. It was necessary to provide against the strata turning out different from what had been anticipated, which generally as a matter of fact was the case and unfavourably for the progress of the work; and in the absence of such provision, many instances had occurred in which borings had been commenced and carried down to a certain depth, and had then been abandoned by the contractor, proving consequently a dead loss. In arranging the charges therefore for the working of the diamond drill, it would not do to base these upon specially favourable cases of borings executed by hand power or by other means, where all had gone well; but it was necessary to average fairly the cost of different works. If the instance were taken of the Middlesbrough boring which had been referred to, executed by the percussive drill, that would give one aspect of the case. If on the other hand the cost were calculated

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of the boring by the same drill at Messrs. Meux's brewery, it would be found to be out of all comparison with the benefit that had at present resulted from it. In other cases that he knew of, where hand boring had been carried out to a certain depth and had then been abandoned, the cost of putting the hole down had of course been excessively disproportionate.

With regard to the boring at Cannock Chase, it was to be expected that the diamond drill, in common with other systems, would not be exempt from failures. They had now been trying since 1873 to put a bore-hole down there by the diamond drill, and after two failures the third hole now in progress appeared to be turning out successfully. As evidence of the difficult nature of the ground to be passed through, he might mention that a hand boring had been reported to have been put down in the same locality to a depth of about 260 ft., and to have then been abandoned on account of the enormous cost, which was said to have amounted to as much as 21*s*. per inch. The first hole bored by the diamond drill went down to 218 ft., and the next to 227 ft.; and each was abandoned on account of having become too small in diameter at the bottom to be continued further. The third hole was already down 300 ft., and he had reason to believe it was now through the pebble beds, having obtained evidence of having reached the strata lying below them. Even had this hole also proved a failure, he considered it would have been no reflection upon the diamond drill; because although he believed the diamond drill to be generally the best for borings, it was not the best in all cases; and in dealing with pebble beds, such as those met with at Cannock Chase, the diamond drill was of no use whatever, and was consequently not employed for that portion of the bore-hole. It was evident that unless the material intended to be cut would stand to be cut, the diamond drill could produce no effect upon it; and upon getting into a pebble bed it was found that the pebbles not only refused to stand to be cut, but they absolutely injured the diamond drill in an extraordinary way. It appeared that they ran round with the tool, and got jammed against the side of the diamonds; and although the diamonds would stand almost any amount of pressure on their face,

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as in cutting solid stone, they became loosened in the crown when subjected to irregular lateral pressure from the pebbles; and as soon as one diamond was forced out, the crown was rendered useless. In dealing with pebble beds therefore the use of the diamond drill was found to be rather objectionable than otherwise. The way in which he tried to overcome this difficulty, and hoped eventually to succeed, was by having a steel crown without any diamonds, jagged with deep teeth somewhat like a crown ratchet, and then hardened to as great a degree of hardness as the steel could be got to stand. Then instead of rotating the crown, the drill was jumped up and down, by means of a winding drum alternately connected and disconnected by a hand clutch with a shaft kept in continual rotation by the engine. In that way he had been enabled to entice the lining tubes down into the gravel, continuously withdrawing the gravel from the inside of the bore-hole as the tubes were got down.

It had not been found possible to carry out this operation with only one length of lining tubes, and the hole was therefore commenced with 8 in. tubes, which were continued down for 60 ft. depth, and then 7 in. tubes were sent down inside them and carried down as much further as could be managed, and so on, continuing to reduce the diameter as the depth increased. The reason why the third hole had succeeded where the two previous ones had failed, was that advantage had been taken of the experience gained in those failures, and the last hole had been begun with a sufficiently large size of lining tubes. He had had a tool made by which the bottom edge of the lining tube could be undercut, for sinking the tube deeper; for the regular boring tool could be no larger than would go down inside the tube, and the tube could only be put down as far as the hole had previously been bored by a larger drill, unless there were some means by which the bottom edge could be undercut. A tool had been made of that character, which would go down inside the lining tube, then expand and undercut the rock below the bottom edge of the tube, and afterwards be withdrawn by levers to its original smaller size, and so be drawn up again through the tube. But he had found that the complications and difficulties involved in a system of that

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kind were not compensated for by the small amount of advantage gained, because in a hard rock, such as the diamond drill was intended to deal with, there was no difficulty as to the sides of the hole standing without any lining tubes; but in softer ground, such as gravel or sand, where tubes would be required, the difficulty consisted not in cutting the ground away, but in driving the tubes down against the great amount of resistance occasioned by the pressure of the sand or gravel surrounding them. For this reason it was considered desirable for the lining tubes now used in borings executed by the diamond drill to be made of a very much better class, as shown by the specimens exhibited, than those employed for ordinary borings; and this was one source of the increased cost of bore-holes put down by the diamond drill.

With respect to the progress made by the percussive drill in the Severn Tunnel, the rate mentioned, if in carboniferous limestone, was a good result to have attained in such hard rock. With the diamond drill working in hard limestone in a level at the Hope Level lead mines near Stanhope, in Durham, the distance driven in one week had been $10\frac{1}{2}$ yards, which he considered very satisfactory indeed; the level had been intended to be 5 ft. wide and 7 ft. high, but 5 ft. width being rather too narrow to drive at any speed, it was being driven 7 ft. square. The average speed hitherto had not been anything like so great, for want of practice on the part of the men working the drill; but he thought that after further practice the diamond drill would be able to average under similar circumstances from 10 to 12 yards per week. The same level had previously been let to miners and driven by hand labour at only about $1\frac{1}{2}$ yards per week, the men working only four days per week and making not more than 18 or 20 hours out of the 24. With the men working in three 8-hour shifts, a level of that kind he considered ought to be driven by hand labour at $2\frac{1}{2}$ yards per week, and this speed would be brought up by the machine to from 10 to 12 yards per week.

With reference to a comparison between the diamond drill and the percussive drills, it had been mentioned in the paper that the advantage of the diamond drill was relatively much less for driving headings than for other purposes; and the reason was that holes of

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moderate depth, such as those required in tunnel driving, could be bored equally well by one system as by another, the question being principally one of relative cost. For holes up to 6 or 7 ft. deep he had no doubt the percussive drill would compare favourably with the diamond drill; with the percussive drill, the holes were put in more rapidly at moderate than at greater depths, and a point of some little practical importance was that they were deficient in the perfect roundness obtained with the diamond drill. One advantage in the diamond drill was the simplicity of its machinery, in consequence of which he had had drills working for a great length of time without getting out of order. Also, owing to the crown drill cutting out only an annular groove round the circumference of the hole, and bringing away the interior portion as a solid core instead of cutting it all out, a hole of 3 in. diameter could be put in pretty nearly as easily as one of 2 in. The drawback to the diamond drill was no doubt the delicacy of the tool itself. A diamond crown, such as the one exhibited, when really well set and in good order and worked with proper care, and when no accident happened to it, was cheaper than a percussive tool, the cost of the wear and tear of the diamonds under those circumstances being less than that of sharpening a steel drill. But such circumstances did not always exist; the diamonds sometimes got broken and illtreated under great pressure, and all this contributed to making the expenditure exceptionally heavy with the diamond drill in tunnel driving. Consequently with the moderate length of holes employed in such work the diamond drill had not the same relative advantage that it had where long holes had to be bored; but there was a large amount of work where deep holes were required, in regard to which he believed no other means of boring could come near the diamond drill.

On getting into soft strata below hard rocks, the course pursued in boring with the diamond drill was exactly the same as with other boring machines, namely to line the hole. He did not think much more lining was required with the diamond drill than with other machines, but care was taken to get the lining tubes down as far as possible, so as to preserve the hole of the same diameter to as

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great a depth as possible. If, after piercing the upper strata, the bore-hole was found to be getting into a formation where it was likely to be troubled with running ground, it was best to withdraw from the hole the lining tubes already down, and then to over-bore the hole to a larger diameter, and put down new tubes of as large a size and to as great a depth as possible, so as to afford an opportunity for reducing the diameter deeper down, if a reduction should be found necessary.

In passing through the bed of salt at Middlesbrough the boring was carried through it without any trouble until reaching the soft strata below, which intervened between the salt and the ordinary harder rock. Then the salt immediately surrounding the hole became dissolved by water trickling down the sides of the hole from the upper strata, and ceased to serve as a guide to the drill; and in that way, as time went on, a continually increasing cavity would have been formed in the salt bed round the hole. A difficulty of that kind could not be overcome any more than in the ordinary system of boring, except by lining tubes; and the better the class of lining tubes, the greater was the probability of getting the hole down successfully.

As regarded the pressure put upon the diamond drill in working, it had been suggested by Mr. Siemens that, if the pressure were too light, it would in all probability result in polishing the stone and not cutting it; and that was exactly what took place in practice. With the diamond crown drill of $2\frac{1}{8}$ in. diameter boring in granite the total pressure required on the whole crown to produce an advance of 4 in. per min. was about 600 lbs. As to drilling with a lighter pressure, in the first experiments made by Mr. Appleby and himself with reference to the introduction of the diamond drill, it had been suggested by Mr. Darlington to try running the drill at an extremely high speed, on the principle by which a piece of soft iron could be made, if sufficient rapidity were given to it, to cut steel. By means of a small turbine the drill was run up to 2000 or 3000 rev. per min. under a light pressure; but the rock then had the best of it, and the diamonds failed, while the rock was not cut. This showed that that was the wrong direction to experiment in, and that a light

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pressure had simply the effect of polishing the rock, and failed to cut it. Experience with the diamond drill had shown that no cutting effect at all was produced, until the crushing point was reached of the rock required to be cut, after which the diamonds destroyed the rock and the cutting action of the drill took place. Bearing in mind the great difference in hardness pointed out in the paper, between the hardest rocks and the carbonate, it was evident that the absolute crushing limit of the carbonate must be very great indeed. One of the best tests whether a piece of stone was carbonate or not was to put it in a vice and try to crush it. In the African diamond fields, where the carbonate was being everywhere anxiously searched for, a material was found very like it in appearance; but the difference was at once detected by this simple test of screwing it up in a vice, which showed that its hardness was not anything approaching that of the carbonate.

In reference to the mode of getting the core out of the hole after it was bored, if the core was hard enough it was frequently left standing while the cutting was continued to the full length of the core tube, which carried the crown drill and formed the bottom length of the boring rods. As the boring rods themselves were of smaller diameter than the core tube, the length of the latter limited the depth that could be bored at one operation; and the length of the core tube was therefore fixed according to the frequency with which it was desired to examine the strata by bringing up the core. As soon as the core had risen to the top of the core tube, the pressure of the boring rods came upon the top of the core, and this together with their rotation almost invariably broke the core off in lengths of from 3 to 7 ft., like the specimens exhibited. As the diamonds on the inside of the crown drill had very little pressure upon them, the core was cut very closely to the diameter of the central hole of the drill; and there was consequently very little chance that the broken length of core would exactly hit this hole as the core tube was drawn up, and so fail to be brought up in the tube. On the contrary the probability was that the broken length of core would catch on one side against the inner rim of the crown, and be prevented from passing through the centre hole, and would thus be drawn up to the

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surface. If the core fell out during lifting, which perhaps might happen once in twenty times, it only dropped to the bottom of the hole, and was brought up again at the next operation. Long cores, like the specimen exhibited, of 3 or 4 ft. length and upwards, very rarely in practice dropped out of the core tube; but it often occurred that the core was found to have been left standing in the bottom of the hole, instead of having been broken off and brought up in the core tube; and the worst that happened then was only that the rods had to be sent down a second time to bring the core out. Another plan for withdrawing the core, when it was not wished to trust to its breaking off in this manner, was to have three self-acting wedges, jagged with ratchet teeth and sliding in slots in the core tube, as shown at A in Figs. 16 and 17, Plate 16, which allowed the core to pass up inside as the crown bored its way down; but on the core tube being lifted, these wedges then gripped the core and broke it off, and brought it up in that way.

For obtaining cores in boring through softer strata, such as coal or clay, or any material that would not otherwise stand to make a core, the way in which the work was done was by having a loose thin tube inside the revolving boring rod; this inside tube remained stationary while the boring rod revolved, and the water, instead of passing down the centre of the boring rod and coming upon the top of the core, as it did in ordinary cases, passed down the annular space between the two tubes; the core was thus protected by the inner tube from being washed away by the water. As soon as the boring had been carried sufficiently far—in the case of coal, as soon as the coal measures had been passed through—the water necessary for boring was shut off, and a few more revolutions of the drill so jammed the debris in the bottom of the core tube as to make a sort of self-acting valve or plug; and on withdrawing the tool, the core being free from any pressure of water on the top, and being thus cemented into the tube at the bottom, was invariably brought up safe to the surface.

Mr. C. W. Siemens observed that, on measuring roughly the area of exposed surface of the diamonds in the specimen exhibited

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of the crown drill, he found the pressure mentioned as being put upon the drill in working must be equivalent to at least 8 tons per sq. in. on the diamonds. It was evident therefore that the carbonate must be an extremely hard material, and a material possessed of a certain degree of toughness to stand such a pressure and the jerks which the grinding action must produce; and doubtless no rock which would be met with in boring would be able to stand against it.

Mr. C. J. Appleby said that, in the experiments with which he had been connected in reference to the introduction of the diamond drill, he had not shared Mr. Darlington's idea that a very high speed of revolution of the drill under a low pressure would produce a better result than the high pressure now used in combination with a comparatively low velocity. In the experiment made to ascertain this point, the drill was run at about 2800 rev. per min., under a total pressure of only about 10 lbs., the intention being to increase the pressure up to a point when the diamonds would not stand it any longer. The drill was tried upon a piece of Dartmoor granite, which was not a very hard stone; and to his great surprise, in a few minutes and before any pressure had been put on beyond the 10 lbs. total upon the drill, the diamonds were completely worn away. As it was thought possible that the diamonds might be at fault, another trial was made with some very good specimens specially selected, which were tested severely before they were set. The result however was practically the same, and it was therefore evident that a high speed with a light pressure was of no use; and this prevented any further experiments in that direction. But he was rather inclined to think that the speed at which the drill was now generally run was nearer the limit of the endurance of the diamonds than was commonly imagined.

There was no question that the results obtained with the prospecting machine were very remarkable indeed and of great value. As to the general question whether for driving headings the percussive drill or the diamond drill was the best, his own experience with the diamond drill and the observations he had

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been able to make on the percussive drills rather led him to think that such work would be done as quickly by the percussive drill and at less cost. A very good percussive drill had recently been designed by Major Beaumont, for use in cases where the diamond drill was not so suitable.

The PRESIDENT remarked that it was now eleven years since he had first brought before engineers in this country—and he believed he was the first to do so—the fact of the existence of the diamond drill; the occasion had been a discussion at the Institution of Civil Engineers upon a paper on the Mont Cenis Tunnel,* in which he had exhibited a small core 1¼ in. diameter sent from France by M. Leschot. Since then, under the care of Major Beaumont, the drill had made very great progress. The present discussion had turned upon the relative advantages of the diamond drill and the percussive drill under various circumstances; and this question had been treated in the most candid manner by the author of the paper, who had brought forward most thoroughly the objections to the diamond drill, where there were objections, and also the merits of rival machines, and thus had enabled those present to judge fairly which under all circumstances was best. Leaving it as a matter for consideration whether the diamond drill was or was not superior to the percussive drill for driving headings and other work of that kind, he thought a strong case had been made out for the diamond drill for great depths and for subaqueous borings; and undoubtedly for the purpose of ascertaining what the bore-hole was passing through, by the ability to raise cores of the rock in its entirety, like the specimens exhibited, it must be admitted that up to the present time there had been nothing which could approach the diamond drill. In the Sub-Wealden boring, the committee, of whom he had the pleasure of being one, were relying upon the diamond drill as the very essence and soul of the undertaking; and in the interest of science it was strongly to be hoped that adequate funds would be contributed for the successful prosecution of so important a work of exploration.

* Proceedings Inst. C. E., vol. XXIII., page 305.

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Another use of the diamond, which showed its power of resistance in comparison with the hardest stones, was for millstone dressing. For this purpose the diamond had been employed most successfully for some years past, though he doubted whether lately the application had been extending. The French burr-stones were probably among the hardest of all stones, and the diamond appeared to be able to contend with them without wearing away materially; but in that instance the effect appeared to be more like cutting than grinding. Only a very light pressure was put on, as all that was required to be produced in the grinding surface was a sort of stone file. He was inclined to think it was a cutting action in that case, but even there it was done by the natural shape of the diamonds themselves, without sharpening them to an artificial cutting edge. He understood from those conversant with the millstone-dressing machines that any attempt to sharpen the diamonds tended to deteriorate their effect upon the work.

He moved a vote of thanks to Major Beaumont for his paper, which was valuable in itself and had also elicited a very useful discussion; and also for the very interesting collection that he had exhibited of cores obtained in different localities by the diamond drill. The motion was carried.

The following paper was then read :—

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DESCRIPTION OF A DIRECT-ACTING CIRCULAR SAW FOR CUTTING STEEL HOT.

BY MR. FRANCIS W. WEBB, OF CREWE.

A large Circular Saw, designed and constructed by Mr. Ramsbottom, has been employed during the last ten years at the Crewe Steel Works for cutting the Bessemer Steel blooms &c. whilst hot, and has been found very efficient and advantageous in economising time and work. The saw is 7 ft. diameter, driven by a pair of locomotive cylinders, 17 by 24 in., running at 100 rev. per min., with a speed at the circumference of the saw of 13,000 ft. per min., or 150 miles per hour. In consequence of the engine running so much slower than the saw, it is requisite to advance the work upon the saw gradually, in order to avoid the risk of "stalling" the engine or breaking the gearing; and in the event of anything failing in the machinery, such as the occurrence of a broken tooth in the gearing, serious damage is likely to arise on account of the high speed of working.

It occurred to the writer that an application of the Brotherhood three-cylinder engine, working direct upon the saw shaft and running at the same speed as the saw, would successfully remove the above difficulties, and would give an important advantage in simplicity and economy of construction. This has been carried out, and the machine is satisfactorily working at Crewe, as shown in Plates 17, 18, and 19. Fig. 1 is a front elevation of the saw and engine; Fig. 2 is a transverse section at the saw; and Figs. 5 and 6 are transverse and longitudinal sections of the engine.

The saw S, Figs. 1 and 2, is 7 ft. diameter and $\frac{5}{16}$ in. thickness, and is mounted between two cast-iron face-plates, leaving 15 in. breadth of the saw projecting clear all round; the teeth are $1\frac{1}{2}$ in. pitch. The saw is fixed on a steel shaft A, 6 in. diameter,

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constructed with two bearings, each 12 in. length; and the shaft is coupled direct to the shaft B of the engine, which is a Brotherhood three-cylinder engine, with single-acting cylinders C C, 14 in. diameter and 8 in. stroke, and internal connecting-rods in the form of simple struts acting upon a single crank-pin D, Figs. 5 and 6. A single cylindrical valve E rotating with the crank shaft serves to supply steam to the three cylinders; and the extreme simplicity of construction of the engine allows it to be driven at a very high speed without any risk of derangement. For meeting the high speed the engine shaft is constructed with a very long bearing F F of phosphor-bronze, 25 in. length and 5 in. diameter, having a central cavity G, Fig. 6, 7 in. long, formed between the main casting and the brass, which is filled with water, and is connected on both sides with the water main. This water supply ensures the bearing being kept cool, and in the event of any warming commencing a circulation of water is set up, which carries off the heat.

A flywheel H, Fig. 1, 4 ft. diameter, is fixed on the saw shaft, with a disc upon its face for coupling with the engine shaft. This coupling is of special construction, for preventing any strain from coming upon the engine shaft in consequence of any slight alteration of level in the saw shaft by wear of the brasses or settling of the foundations. The coupling, which is shown in Figs. 3 and 4, Plate 19, consists of two discs J and K, 18 in. diameter, one keyed on the end of the engine shaft B, and the other bolted to the face of the flywheel H on the end of the saw shaft A; and an intermediate steel disc or driving plate L, $1\frac{1}{2}$ in. thickness, fits close between them, having two projecting ribs with square edges, one on each face, 4 in. width and 1 in. projection. These two ribs are at right angles to each other, as shown in Fig. 4, and fit into corresponding grooves in the face of the two outside discs J and K upon the shafts, and serve as a coupling between the shafts. The driving plate L is loose between the discs J and K, and would thus allow the two shafts to be out of line without causing any strain; and the two ribs being at right angles upon it prevent it from getting displaced.

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The work to be cut is brought up to the saw by a travelling table M carried on wheels, Figs. 1 and 2, similar to the table used with the original saw, and moved by a rack and pinion with a double winch N worked by two men. A stop block P is provided, with a screw retaining-claw R for holding the work during the process of sawing.

This simple construction of saw, with the direct-acting and continuous driving power given by the three-cylinder engine, has such complete command over the work, that a large steel ingot can be pushed forward rapidly upon the saw without risk of "stalling" the engine or of any accident from failure of gearing. The action of the saw in cutting a large steel ingot is quite smooth, and as easy as that of an ordinary rail saw. A jet of water plays on the saw when the cut is heavy, to prevent the teeth getting overheated. A steel ingot 10 in. square is cut through in 25 sec. with 50 lb. boiler pressure of steam; and a larger ingot 20 in. diameter has been cut through by two cuts, one from each side and meeting in the centre, and the end of a crank slab 22 in. by 12 in. has been cut off in 3 min. 5 sec.

The use of these large saws has proved very advantageous in making steel forgings, by giving the means of cutting the Bessemer ingots accurately to the sizes required to be made, so as to avoid surplus material; and an important saving of time and of re-heating is effected, as this cutting is done at the first heat, the ingot being brought to the saw whilst hot from the hammer. The saw is also used for cutting out crank axles, and gives the means of roughing them out very close to the finished dimensions. Further applications of the saw are contemplated; for instance, cutting rails for making points, by setting the rail to travel up to the saw on an inclined bed giving the required taper in the cut. A saw of half the diameter is proposed for that purpose, driven at double the number of revolutions per min., so as to give the same velocity of circumference as in the large saw.

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Mr. Webb exhibited a specimen of the end of a steel ingot 20 in. diameter, and a slice $1\frac{1}{4}$ in. thick from the end of a crank slab 22 in. by 12 in., which had been cut off by the saw; he explained that they were intended to show, not so much the smoothness of the surface left by the cutting, as the amount of material that was removed in so short a time by the saw, the width of the cut having been $\frac{7}{8}$ in. During the last two or three years he had made a practice of running up a saw cut as far as possible in each of the cranks when forged, and then annealing the whole, keeping it 24 hours in the annealing furnace at as high a heat as could be maintained without injuring the steel, so that all the particles might be set at rest before the cranks were turned out. If the particles were not set at rest before the crank sweep was cut out, the crank almost invariably took a set one way or the other of $\frac{1}{4}$ to $\frac{5}{16}$ inch out of truth, showing that it was ready to break at the first opportunity. Since this had been done, the breakages of crank axles had been reduced, though the work performed had increased 20 per cent.; the breakages had previously amounted to 160 crank axles per annum in the locomotives of the London and North Western Railway, but latterly the number had been only 106. That was a step in the right direction, and he hoped in a short time to be able with this saw of $\frac{5}{16}$ in. thickness to rough out the cranks ready for the finishing cut, by taking out a cut of $2\frac{1}{2}$ or 3 in. width. This might be done by means of a drunken saw, but he preferred to do it by setting the teeth over sideways to a sufficient extent; in the experiments made for this purpose he had already succeeded in cutting out 2 in. width.

The mode of coupling the engine shaft to the saw shaft, by means of the intermediate loose disc with ribs at right angles, was the same that had been used previously in the manufacture of Bessemer steel for turning the converters over. It had been found to work so well there, that it had occurred to him to apply it for driving the saw.

With regard to the mode of driving, the saw described in the paper was not the first that had been driven by a three-cylinder engine, the first saw so driven having been put down on his

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recommendation for cutting steel rails at the Bolton Iron and Steel Works, where up to the present time it had been working night and day, and had cut 20,000 tons of rails.

Mr. P. Brotherhood said the rail saw at the Bolton Iron and Steel Works had now been running about fifteen months, driven by the three-cylinder engine at between 700 and 800 rev. per min. The engine had been taken to pieces a few weeks ago for examination, and there was found to be not the slightest wear on the crank-pin; the connecting-rods were slightly worn, and the crank-shaft bearing was also slightly worn. But nothing was required to be done to it, and it was therefore put together again just as it was; it was still running, and he did not know how long it would last.

Mr. H. Woods enquired what sort of packing was used for the pistons of the three-cylinder engine driving the saw, and how long it lasted.

Mr. P. Brotherhood replied that the pistons were made very deep, and were fitted each with two Ramsbottom rings set together in one groove, with the joints at right angles, so that one ring should spring in one direction and the other in the opposite. He could not tell how long the rings would last, as they showed at present no signs of wear. He had had some of the three-cylinder engines running without any packing at all but merely small grooves.

Mr. Webb said that in locomotives those packing rings often ran for twelve months, if they were working in a good cylinder.

Mr. P. Brotherhood mentioned that in the instance of another circular saw 4 ft. 6 in. diameter, which he had made for cutting off the ends of steel rails, the saw and engine were mounted bodily on a travelling frame and ran at 1200 rev. per min.; the rails were brought up in front of the saw, which was then advanced upon

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them by a steam cylinder at the back, the motion being controlled by a hydraulic regulator.

The President enquired what was the advantage of that method as compared with the ordinary plan of moving the rail up to the saw.

Mr. P. Brotherhood replied that it avoided the necessity for making heavy machinery and a long carriage to bring the rail up to the saw, and the weight to be moved was lighter.

Mr. R. Price Williams thought the saw would afford the means of arriving at a great improvement in railway crossings, not in the way pointed out in the paper by tapering the ends of the rails, but by a simple method, suggested by Mr. Webb some years ago, of splitting up a rail rolled to double the width of the usual section. The double rail was first split up longitudinally by a central saw-cut as far as the junction of the main-line rail and the siding rail, and one half was then bent outwards to the required angle of the siding rail, so as to form the V piece of the crossing; the point of the V was formed by planing out an oblique groove at the same angle across the double rail. By this means the continuity of the main-line rail was preserved throughout the whole length of the crossing. This arrangement he thought would greatly add to the safety of the line, as the weakest part of the road at present was certainly at the crossings. If ordinary crossings were used, the continuity of the main line was broken, and it was practically impossible to prevent a vertical movement in the point of the V piece. If solid crossings were used—except at principal stations and in sidings where the speed was slow—they acted as anvil blocks in the road; and their destructive effect upon the rolling stock, where the trains passed over them at any great speed, was so well recognised that their use in the running road had been entirely abandoned on railways in this country. If by the use of this saw an inexpensive crossing could be obtained, which would preserve the continuity of the main-line

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rail, a very great improvement would be effected in the permanent way of railways.

Mr. R. H. TWEDDELL understood that at Messrs. John Brown and Co.'s works at Sheffield steel rails were being cut by a circular saw without any teeth, simply a plain steel disc running at a very high velocity; and he should be glad to know whether Mr. Webb had tried this experiment, because if it were the case that the same result could be obtained without teeth to the saw, it seemed to be an unnecessary expense to make them.

In a recent instance in which he had had occasion to recommend the use of a circular saw for cutting rails and bars, he had adopted hydraulic pressure for traversing the saw up to the work; when first started the pushing power was too great, and the saw had been choked by being advanced upon the work too fast, but this had now been overcome by admitting the water more slowly.

As regarded packing, it seemed to him that it would be possible with an engine running at such a high speed to do without any packing at all; the pistons were very deep, and if simply grooved he thought they might be tight enough without packing. This suggestion was only made on the supposition of the Ramsbottom packing rings ever giving trouble; but he did not think they would do so, from the experience he had had of their use in these three-cylinder engines.

Mr. L. OLRICK enquired whether there had been any opportunity of measuring the amount of power which had been saved by driving the saw direct and thereby avoiding the use of the gearing previously employed for multiplying the speed five times. He asked whether there had been an opportunity of measuring the actual horse power used in the two systems, as the indicated horse power would be no criterion, on account of the great amount of power lost in friction when the gearing was employed.

Mr. WEBB replied that he had not had an opportunity of comparing the results of the two modes of driving the saw, in regard

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to the power required; as far as economy of steam was concerned he did not think there was much difference. But after there had been accidents with the previous machinery, the gearing having been sent flying through the roof twice, and the engine house knocked down, he thought it was requisite to devise something more economical in machinery and less dangerous to the men attending the saw. This had been his principal motive in adopting the direct-acting mode of driving; but he could not imagine that with an engine running at so high a speed, and having a flywheel on the saw shaft, there could be less economy than with the previous engine of ordinary locomotive construction driving through gearing and without any flywheel.

He did not see what there was to be gained by cutting rails without teeth on the saw, and was not aware that that plan was being continued at Sheffield. The teeth on the saw described in the paper would last for many weeks, only requiring to be set up occasionally during that time with a hammer and chisel.

The PRESIDENT was sure the meeting would give a vote of thanks to Mr. Webb for his paper; although it was a short one, it brought to notice the working of a practical machine, the results of which were seen in the specimens exhibited of ingot ends cut off by the saw. It showed the means also of doing that which was most desirable in the manufacture of crank axles, namely getting them into such a condition that the internal strains were settled before the cranks were completed. No doubt that was a very great element of safety.

The vote of thanks was passed.

The following paper, communicated through the President, was then read:—

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ON THE FLOATING SWIMMING BATH AT CHARING CROSS, WITH THE MEANS ADOPTED FOR THE FILTRATION OF THE WATER.

BY MR. EDWARD PERRETT, OF LONDON.

In 1873 Mr. C. W. Whitaker and the Author were appointed Engineers to the Floating Swimming Baths Company, established for the purpose of providing floating baths at any available locality, but especially upon the river Thames. At that time the company proposed to use a plan for floating baths, in which the most noticeable feature was, that when desirable the water should be filtered by passing through charcoal before being delivered into the bath.

It was at once apparent to the author that such means would be quite inefficient and very expensive, and that until a more satisfactory system of filtration could be adopted, the project of providing baths on the Thames or elsewhere, in which filtration of the bathing water should be necessary, must remain in abeyance. After some consideration however it was determined at the instance of the author, to institute a series of experiments in filtration, on a scale sufficiently extended to give reliable results.

Preliminary Experiments on Filtration.—Two descriptions of material were fixed upon for trial, namely Ransome's stone filters and the ordinary bag filters used in sugar factories. The stones used were of various degrees of porosity, and formed into hollow cylinders with one end closed, to give surface; these were placed in the tank containing the water to be filtered, as shown in Fig. 10, Plate 22, the closed end being uppermost, and the open end resting upon a saucer provided with an india-rubber joint and an outlet pipe, which passed through the bottom of the tank, and was there

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fitted with a cock. The bags were the ordinary cotton bags used in filtering sugar, each in a netting to prevent distension, and attached by a brass mouthpiece or bell to the bottom of a tank containing the liquid to be filtered, as shown in Fig. 11. The apparatus thus prepared was placed upon a barge moored on the site proposed for the Pimlico Floating Bath, so that no question might subsequently arise as to the quality of the water operated upon, in comparison with that to be thereafter supplied to the projected bath. The water was pumped into the filter tanks direct from the river.

Not to go too fully into detail, it may be stated briefly that the best result obtained by the stone filters, having about 5 sq. ft. of surface, was a yield of fair water amounting in the first 4 min. to 50 gall.; in the next 5 min. to a further 50 gall.; in the following 6½ min. to 50 gall. more, thus reaching 150 gall. in 15½ min.: and so on, until at the end of 30 hours the yield practically ceased, having then amounted to about 1000 gall. of very fair water. Although the performance of these filters was so far highly satisfactory, no ready means of cleaning them for repeated use could be suggested, especially on account of their extreme friability; and the price of new ones being about £1 each, the cost of constant renewal could not be incurred, and it was therefore decided that they could not be adopted.

The trial of the bag filters gave the following result. From one bag, having a surface of about 20 sq. ft., a yield was obtained of 50 gall. in 5 min., a further yield of about 50 gall. in the succeeding 9 min., and a further quantity of 50 gall. in the next 45 min.: making 150 gall. of very clear water in the hour, at the end of which time the delivery practically ceased; the bag had then merely to be removed and washed, and when replaced was again ready for use. As these bags with their sheath are comparatively inexpensive, costing from 5*s*. to 6*s*. each, and can be arranged about 5 in. apart from centre to centre, and are durable and readily cleaned, it was considered that sufficient information had been obtained to warrant application being made to the authorities for permission to place floating baths in the river Thames.

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But it was still felt that the process of cleaning the bags by taking them down, removing them from the bells, and washing them, was attended with inconvenience and expense which it would be very desirable to overcome or to diminish. Some means was therefore sought for cleaning them without removal from their places; and a further series of experiments was carried out by the author to try the effect of what may be termed a "blow-through" filter, as shown in Fig. 12, Plate 22. This consisted of a modification of the ordinary bag filter, by placing an additional bell at the lower end of each bag, precisely similar to those by which the bags are suspended, the lower bell leading through the bottom or side of the vessel that receives the filtered water, and being provided with a cock. This apparatus, as in the former case, was placed on board a barge moored in the Thames, the water being drawn from the river as before; when the bag, from accumulation of dirt in the interior, gave sign of slackening its yield, say at the end of 15 min. work, the cock upon the lower bell was opened, and the water rushed through the bag, partially cleaning it, so that when the cock was closed again the bag at once recommenced filtering. This experiment was so far successful that it was found by this arrangement one bag will yield about 500 gall. before it need be removed and washed. It should be borne in mind that the water under treatment was heavily charged with extremely fine particles of matter in suspension of a slimy nature, as may be seen by the sample exhibited.

A notable feature arising out of these experiments, and one on which the author would be glad to have the opinion of members of the Institution, is that the water which, in the former series of experiments, had been filtered through the stones, upon being opened after a few weeks, emitted a powerful and very unpleasant smell, though not so strong as that given off by the unfiltered sample; whereas the specimen taken of that which had been filtered through the bags, though opened at the same time, did not then and has not since emitted any odour at all.

Of the samples exhibited, Nos. 1, 2, and 3 were taken at the time the first series of experiments was made; and Nos. 4 and 5 were taken only two days ago.

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No. 1.—Thames water	unfiltered		Taken at Pimlico, 23 October 1873.
No. 2.— „ „	filtered through the stones		
No. 3.— „ „	filtered through the bags		
No. 4.— „ „	unfiltered		Taken at Charing Cross, 27 April 1875.
No. 5.— „ „	filtered through the bags		

The growth observable in the filtered water, samples Nos. 2 and 3, became apparent some four or five months after the date of the experiments, up to which time the water was perfectly clear and bright, similar to sample No. 5.

The first series of experiments extended over three weeks, during the whole of which time the men employed on board the barge drank the water from the bag-filter receiving-tanks. No attempt was made to free the water from chemical impurity, as it was believed that the removal of the mud, coupled with the aeration effected by the spreading of the water in an almost imperceptible film over the surface of the bag in the process of filtering, would purify the water sufficiently for all the requirements of bathing. Particulars of the method of applying this system of filtration are given subsequently.

Site of Bath.—Permission was then obtained from the Thames Conservancy Board and the Metropolitan Board of Works for a floating bath to be placed in the recess of the Victoria Embankment, immediately west of the Charing Cross railway bridge,—a site unrivalled in point of position, being exactly opposite the junction of the Victoria Embankment and the new street now being made from Charing Cross, but presenting such engineering difficulties as induced the author to recommend the substitution of one further out in the river, under the shelter of the main pier of the railway bridge; access to the bath could then have been gained from the foot bridge by a spiral staircase terminating in a brow. In that position the bath would have been always afloat, and what is of still greater importance, the water there is much cleaner, containing perhaps less than half as much mud and other impurity as is contained in the water nearer the shore. This recommendation however was not acted upon.

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The site selected in the recess of the embankment, Fig. 5, Plate 20, was at that time occupied by a dumby or landing stage for river steamers, but not in use for that purpose. The bottom of this recess is formed by a sloping stone apron, Fig. 4, wide enough to carry the dumby when the tide fell low enough to strand it, which happened but rarely, as the dumby drew very little water. This apron was not wide enough however to carry the bath, which projects some 10 or 12 ft. beyond the apron, and draws some 8 ft. of water. The greater width of the bath and the slope of the apron rendered necessary the preparation of a level bed to receive the bath at low water. This was done by driving piles in the river bed about 6 ft. apart from centre to centre, under the line of the outer edge of the bath, with capping from which horizontal timbers also 6 ft. apart run back to the embankment wall in the recess, as shown in Figs. 3 and 4; other timber fixings are arranged as shown in Fig. 4. The gridiron thus forms a level bed for the flat bottom of the bath to rest upon at low water.

Construction of Hull.—The hull of the bath is entirely of wrought iron, and is shown in the sections and plan, Figs. 3 to 5, Plate 20, and the enlarged cross section, Fig. 6, Plate 21. It consists principally of two longitudinal box girders A A, 2 ft. 6 in. wide and 177 ft. long, forming the sides of the bath, with a depth of 10 ft. 6 in. at the centre for a length of 42 ft. 6 in., and 9 ft. depth at each end for a length of 18 ft., and 8 ft. depth for the intermediate lengths, as shown in Fig. 3. These girders are placed 25 ft. apart, connected together at the ends, and further tied by two transverse bulkheads 21 ft. from each end: giving a bathing area B B of 135 ft. length and 25 ft. breadth, and two chambers C C for machinery &c., each 21 ft. × 25 ft., one at each end of the bath. The whole of the plating is $\frac{1}{4}$ in. thick, with the exception of the keel-plate and garboard-strake, which are $\frac{3}{8}$ in. thick, the bilge-strake, which is $\frac{5}{16}$ in. thick, and the top plates of the girders, which are $\frac{3}{8}$ in. thick. The bathing area amounts to 3375 sq. ft., and when full the bath contains about 150,000 gall. of water.

The water in the bath being filtered, it was necessary to provide a bottom to the hull; this forms a further connection

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between the side girders. In cases not requiring the bathing water to be filtered, no bottom would be wanted except for the safety of the bathers. The bathing space is provided with a wooden false bottom, resting on the main frames at the western end, giving a depth of 6 ft. 3 in. of water for a distance of 50 ft., and thence sloping gradually upwards to the eastern end, where the depth of water will be about 2 ft. 6 in., as shown in Fig. 3. These depths may however be increased 8 in. or 9 in. if found desirable.

The occasional grounding of the bath rendered necessary still further connection between the two sides in the 135 ft. length of the bathing space, as at such times the water inside the bath would be some 4 ft. or 5 ft. higher than that outside. To effect this connection, two curved bridges D D, Figs. 4 and 6, are placed near the ends of the 10 ft. 6 in. central part of the side girders, dividing the bathing space into three about equal portions, Fig. 5. These bridges are not arches, but bent girders of exceptional strength: the object of the curvature being to afford an uninterrupted view from end to end of the bath, which could not have been obtained if these connections had been horizontal, as would have been preferable, if they had been considered merely as ties. A bottom having been provided, it was requisite to make it strong enough to bear the upward pressure of the water outside when there is no water inside the bath, as in the progress of the erection of the superstructure, or during repairs &c.; accordingly 7 in. main frames are placed at every 6 ft. with reversed bars, and intermediate frames at every 2 ft.; a rider-plate centre-keelson E and sister-keelsons F are also provided, as shown in Fig. 6. The timbers of the gridiron correspond with the main frames.

The frames in the two end compartments C C are placed 4 ft. apart from centre to centre, with an intercostal keel; and generally the work is of greater rigidity in these portions of the structure. These end compartments are further strengthened by transverse beams, of bulb and double angle-irons, which form the roof or deck of the chambers, and the floor of the rooms above. Along the river side and the ends of the bath the outer skin is carried up to a height equal to that of the deepest part of the girder, 10 ft. 6 in.;

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and upon it is placed a horizontal plate 12 in. by $\frac{3}{8}$ in., strengthened at every 3 ft. by a knee, forming a convenient platform on which to erect the superstructure, and also serving to carry the timber fender placed along the outside. The top of the side girders forms the footway round the bathing space, and the floors over the end chambers are raised 1 ft. above the top of the girders.

Mooring.—The question of mooring the structure presented more than ordinary difficulty. Owing to the site being in a recess of the embankment, and close to the steam-boat pier, the bath must be kept in approximately one position; chains therefore could not be used, while at the same time provision had to be made for preventing, in the event of high winds, all the strain falling upon rigid moorings. Another essential consideration was that the bath should be easily and rapidly placed in position, and as readily removed if necessary.

To this end, four cast-iron guides G G, of the section shown in Fig. 9, Plate 22, are bolted vertically to the embankment wall, in the positions indicated in Fig. 5. These guides are 30 ft. high, extending about 8 ft. above high water. In the longitudinal girder of the bath on the embankment side are placed four pairs of T headed bars, corresponding in position with the cast-iron guides G G; the tails of these are screwed and passed through long bosses H H on the inside and outside of the girder, india-rubber washers and gun-metal nuts and lock-nuts J J being put on the screwed ends. In the inner boss, and in the tail of each T bar, is cut a long cotter-way, which, while not interfering with play of the bar endwise, prevents circular movement when cottered up.

When the bath was brought into position, these cotters were withdrawn, the T heads were turned into a vertical position, and thus passed without difficulty into the guides. They were then turned back into their proper horizontal position, thus engaging the cast-iron guides, the cotters were put in, and all was secure. The operation of getting the bath into position occupied but a few minutes from the time of its arrival alongside, and removal could be as easily accomplished. The screws on the tail of the T bars enable a

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perfect adjustment to be made, so that each guide shall do its share of duty; the india-rubber washers serve to deaden the shocks that arise from the movement of the bath caused by passing steamers. In the neighbourhood of these guide bars the girder is well strengthened with angle irons and plates to prevent injury to the structure. Stiff adjusting buffers are placed at each end of the bath to prevent motion endwise.

Supply of Water.—The apparatus for supplying the bath with water is arranged in accordance with the experiments already described, and is shown in Figs. 7 and 8, Plate 21: Fig. 7 is a transverse section of the machinery chamber C, which is the one at the eastern or shallow end of the bath, Fig. 3; and Fig. 8 is a corresponding plan. Each bag filter being capable of filtering say 500 gall. of water, and the bath requiring about 150,000 gall. to fill it, 300 bags are wanted for the purpose; and these delivering the water into the bath at the rate of say 500 gall. per minute, the operation will take about 5 hours. Running along each side of the machinery chamber is a shallow tank K, which is divided into compartments, and placed at such a height that the bottom shall be about 1 ft. below the water line of the river when the bath is full and afloat. Into the bottom of each of these tanks are inserted 300 brass bells, the upper portion of each bell being fixed in the tank bottom, and the lower or trumpet-mouthed portion connected to it by a coarse-threaded screwed end. Below these tanks are placed other tanks M to receive the filtered water, each 21 ft. long, 3 ft. wide; and 3 ft. deep, the bottom of the lower tanks being about 5 ft. 6 in. below the bottom of the upper. On the river side the lower tank is provided with a false bottom, Fig. 7, into which are inserted bells similar to those in the upper tank, but inverted; and the space L between the false and real bottoms is divided into compartments, corresponding with those in the upper tank; each of these compartments is provided with a large valve V to draw off its contents. The portion of this lower tank above the false bottom communicates with the pumps, and the upper shallow tank is in communication with the river by means of pipes P passing

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through the side girder. On the land side, the upper tank is in communication with the interior of the end of the box girder, which again communicates by the pipe R with the bath. The lower tank on this side has no false bottom, but is in direct communication with the pumps. Filter bags are connected on the river side to the bells in the upper and lower tanks; these bags on the land side are merely suspended from the bells in the upper tank, the lower ends not being open as those on the river side are, as shown in Fig. 7.

Water is admitted from the river at pleasure to any or all of the compartments of the upper tank on the river side, and passing down through the bags fills the space L below the false bottom of the receiving tank, and filters into the latter above the false bottom; thence it is pumped into the bath, while the mud and matter that was in suspension in it settle in the space L under the false bottom or on the sides of the bag itself. When after a time the yield from the bags in any compartment partially ceases, the large valve V in the bottom of that compartment of the tank is opened, and the dirt is swept out by the flow of water into the bilge, whence it is pumped overboard by the donkey pump; the greater portion of the matter adhering to the bags being removed by the rush of water through them, they will recommence filtering as soon as the valve is closed again, though the yield may be somewhat less than before. When, after repeated application of this means of cleansing, the filtration slackens considerably, the bags may be removed by unscrewing the trumpet mouths to which they are secured at top and bottom, and may be released from these trumpet mouths, and washed.

On the land side the water from the bath passing into the end of the box girder may be drawn at pleasure into the upper tank, whence it re-filters through the bags into the lower tank, and is pumped from there back into the bath again: for this purpose it was not thought necessary to provide the blow-through apparatus for cleansing the bags. The water from the bath passes also into the end of the box girder on the river side, so as to balance that in the girder on the land side; and is also admitted into the corresponding

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portions of the box girders at the other end of the bath, in order to equalise the strain upon the entire structure and to keep it on an even keel.

The pumping machinery was intended to consist of two of Messrs. Gwynne and Co.'s 7 in. centrifugal pumps, with 3 ft. 6 in. discs, each capable of delivering 750 gall. per min. against a 25 ft. head at 280 rev.; but the contractors for the machinery have at their own risk substituted pumps of their own make to do the same duty, the discs being only 2 ft. 3 in. diameter. The pumps S, Figs. 7 and 8, are arranged to draw either from the filtered-water tanks M, the bath itself, or the bilge; and to deliver either into the bath through the fountains placed in it, Fig. 2, or into the upper filter tanks K, or overboard, as may be required. For first filling the bath the pumps draw from the bilge, into which the water is allowed to enter direct from the river through cocks provided for this purpose. The overflow from the bath passes off through two self-acting subsiders placed in the chamber C at the western end of the bath. There being abundance of water, a Morton's ejector-condenser is applied to each of the pump cylinders, drawing its supply of water from the bath and delivering into the suction main of the pumps. Steam is supplied by a 14 H. P. semi-fixed boiler of the ordinary type, but with two fire-doors for accommodation in firing. A washing and a rotary rinsing tank are provided for cleansing the bags when they become choked.

An apparatus for raising the temperature of the water in the bath has also been provided; it consists of four fire-tubes, in pairs, placed below the sloping bottom of the bath, and stoked from the machinery room. Each pair of fire-tubes runs into a common flame-box, and the gases are returned through 3 in. tubes to the front, where they go into a common uptake which passes through the dressing room over the machinery room, serving in cool weather, when the water is warmed, to warm this dressing room; the uptake acts also as an air space around the chimney from the steam boiler, serving to prevent this from warming the room in hot weather. It is not proposed to warm the water during the winter, but only to extend the bathing season by heating the water say in May and

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October, the temperature of the water in the neighbourhood of the bath being on an average as follows, according to observations made in 1873:—

May	June	July	August	September	October
55°	62°	65°	66°	60°	56°

Superstructure.—It was originally intended that the main ribs of the superstructure of the bath should be of wrought iron, forming in fact continuations of the ribs of the hull; but the appearance of this was not considered suitable to the site. The first design, which is represented in Figs. 1 and 2, Plate 20, was composed principally of cast iron and glass; but owing to its costliness, and to difficulties with the contractor at the outset, causing much delay, it was decided to adopt a plan which could be more readily and cheaply carried out, though less ornamental, and into the construction of which timber should enter more largely; it will retain however the same outline, and present the same general appearance as the former design.

The two domes are each 30 ft. square and 30 ft. high, and are placed 18 ft. from the ends of the bath; the portion between the domes is 20 ft. high, and the rooms over the end chambers are 10 ft. high. The iron columns of the domes are 6 ft. apart, terminating in curved ribs, which are connected together and supported by brackets. In the intermediate portion the columns are placed 12 ft. apart, carrying a roof similar to that of the domes. The curved portion of the roofs is covered with boarding and zinc work; the upper portion is glazed, and provided with continuous louvre ventilators. The roofs over the end chambers are flat and covered with zinc. Wood frames are placed between the iron columns to receive the sashes, which are glazed, like the skylight, with ribbed glass.

The dressing boxes T, Fig. 2, are on the land side only, and are supported on iron brackets; they are so placed as to coincide with the recesses in the embankment wall, Fig. 5. The room over the machinery chamber is formed into a public dressing-room, and that over the opposite end chamber is arranged as a refreshment room,

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with plate-glass windows, affording a view over the river. Under the domes are placed the fountains for delivering the water into the bath. The pay office is placed on the floating stage that carries one end of the brows by which the bath is reached from the embankment.

Filtration.—As probably the portion of this paper most likely to be of interest to the members of the Institution is that relating to filtration, it may be desirable to refer to the various methods that have been investigated by the author since the subject has engaged his attention, with the various results arrived at. It may be assumed that water may be filtered through cloth, charcoal, sand, porous stone, &c., with approximately similar results. The question of the most suitable material would appear to resolve itself into the enquiry as to which can be most easily and readily cleansed. For the purposes of baths, the effect of filtering the water through bags was quite satisfactory, but the system in practice for cleaning the bags was very imperfect; and although the method to be adopted in the Charing Cross bath had been decided on and the machinery ordered accordingly, yet the author determined to go further into the question of filter cleansing.

The first filtering apparatus with mechanical means of cleansing that was tried by the author is shown in Fig. 13, Plate 22. The filter cloth being spread over a stationary perforated drum D carried on a vertical spindle in a tank A, the liquid to be filtered was put into the annular space between the drum and the tank, and filtered into the inside of the drum, leaving the dirt on the outside of the cloth, the filtered liquid being drawn away by the self-acting syphon B. When it became necessary to cleanse the filter, the tank cock C was opened, and the liquid in the annular space, into which much of the dirt had settled, was drawn off. The drum was then rapidly revolved, a very little clean water being introduced inside it by the sparger pipe E; the dirt was thrown off, and the cloth became as clean as though it had never been used. The mud &c. ran off through the draw-off cock C, and the filter was ready to start afresh. But although the result of this method was

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satisfactory, and the quantity of clean liquid per sq. ft. of filtering surface was largely in excess of that obtained from the bags, yet it was apparent that owing to the size and cost of the apparatus, compared with those of the bags, in relation to the work done, it could not successfully compete with the bags unless means could be devised to accelerate the filtering.

Trial was next made of an apparatus consisting of a rapidly-revolving horizontal disc of thick cloth split horizontally at the edge, one portion of the split edge being turned or dished upwards and the other portion downwards. The liquid to be filtered was discharged upon the disc, at some distance from its centre, in a small stream and under pressure. It was supposed that the momentum of the stream would carry the liquid some way into the cloth or through it, leaving the particles of dirt entangled at or near the upper surface of the disc, and that the filtered liquid would by the centrifugal action be thrown off from the underside, and directed downwards by the under lip of the disc, while the impurities would be flung off from the upper side by the same means. The result of this trial however was not satisfactory, for the liquid when delivered at any appreciable distance from the centre of the disc did not penetrate the cloth in any quantity, and that which did was not clear; the major portion of the liquid was thrown off the disc in a partially cleansed condition, some of its impurity having become entangled in the cloth, but this dirt was also thrown off the edge a few moments later than the liquid.

A further trial of centrifugal filtering and filter cleansing was then made with an apparatus shown in Fig. 14, Plate 22, consisting of a vertical spindle carrying a wire-work basket, to the upper edge of which was attached one end of the filter cloth I; this hung downward inside the basket, and was brought up again to a disc G which was fitted with a nut capable of working up a screw contained within a hollow and slotted prolongation of the vertical spindle; at the top of the screw were fixed a few fan blades H. The liquid to be filtered was run into the annular space formed by the hanging filter cloth I; and the apparatus being put into motion, centrifugal action drove the liquid through the cloth into

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the lower chamber J, leaving the impurities inside the cloth. When it was desired to clean the filter, the speed was accelerated; the increased resistance of the air to the fan blades then caused a retardation of the screw, by which the nut attached to the disc was made to ascend, and the cloth being thus turned inside out, as shown dotted at F F, the dirt was thrown off into the upper chamber K. The speed then being reduced, the cloth returned to its original position. The quantity of filtered liquid yielded per sq. ft. of surface was greater than that delivered by the stationary filter shown in Fig. 13, but it was not sufficiently clear for the purpose for which it was wanted. From this circumstance it was gathered that filtration could not be successfully effected while the filtering material was in motion, as the slightest disturbance of the filtering material appeared to be sufficient to permit the passage of enough dirt to make the filtered liquid cloudy; but on the other hand, centrifugal cleansing of the filtering material was found to be thoroughly practicable and successful.

Guided by the above results, it became necessary to devise an apparatus giving ample quiescent filtering surface, and capable of being easily cleansed by centrifugal action. Many plans were considered by the author, but the most suitable that has yet occurred to him is shown in Fig. 15, Plate 22, which is a modification of that shown in Fig. 13, and consists of eight pairs of perforated discs D D bolted together and covered with filter cloth, and carried upon a hollow spindle through which the filtered liquid runs off at B. When it is required to clean, the outside liquid is drawn off at C, and the discs are rapidly rotated, as in the case of the drum in Fig. 13; the cleansing can be assisted by the admission of a little clean water through the central perforated pipe E if required. A filter of this description, with eight pairs of 5 ft. discs, giving a filtering surface of over 500 sq. ft., and cleansed by rotation say every 15 min., would be capable of yielding 10,000 gall. of clean water per hour: the water operated on being similar to the sample No. 1 exhibited.

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Mr. PERRETT exhibited the several samples of filtered Thames water referred to in the paper, and also specimens of the stone filter that had been tried, and of the cotton filtering bags and the netting enclosing them. He mentioned that a sample of water taken from the Thames a few days previously at the site of the Charing Cross bath had been found to contain 1-1400th part of its weight of solid matter in suspension. The rate of filtration with the blow-through bag-filter had been found to be 500 gall. from one bag in about five hours, and the gradual choking of the bag by the mud was shown by the fact that the first 100 gall. passed through the filter in 15 min., the second took 22 min., the third 61, the fourth 72, and the fifth 130 min.; the bag being partly cleansed by blowing-through with the unfiltered river water after every 100 gall. was then ready to start filtering again.

Mr. E. A. COWPER enquired what was the rate at which it was intended that the bath water should be changed. The bath was to contain 150,000 gall. of water, and it had been stated that by means of the bag filters the water could be delivered into it at the rate of 500 gall. per min. or 30,000 gall. per hour; but he presumed it was not intended to change the water so frequently as once in every five hours, for if that were done the water would of course be remarkably clean. In the London swimming baths he believed the water was generally changed about three times a week. The number of dressing boxes seemed to him rather small, being apparently only forty-six; in a bath of that description he should certainly think that a hundred might be used in summer, and he hoped the bath would be so popular that the numbers would have to be increased. He enquired whether the engines pumping the water into and out of the bath were non-condensing, or whether they had surface condensers, so as to give clean warm water free from grease; in which case he suggested that the exhaust steam might be easily and economically utilised for taking the chill off the water when it was rather cold, because there was no doubt that swimming baths were more popular if the temperature of the water was raised a few degrees above that of the river, not so as to make it warm, but slightly tepid; and the

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exhaust steam from the engine might be applied to that purpose. He felt a great interest in the success of the bath, having himself previously endeavoured to get baths established on the Thames, for which he had proposed to use the water from the water works, bringing it over the bridge on the land side into the bath. That plan he thought would probably have cost rather more than the filtration of the river water, though perhaps the water might have been a little better. The sample exhibited of the river water which had been filtered through bags two days previously had not yet had time to putrify, and certainly looked very clean, and was good enough for bathing, although perhaps not clean enough for drinking; because, after all, filtering through bags was only straining the mud out, and was not such a filtering as through charcoal or fine sand; but the result would be very satisfactory if the water supplied to the bath was always as clean as the sample exhibited. The proportion of solid matter in the water before filtration being 1-1400th, he should be glad to know how much of that was taken out of it by the filtering bags, as the actual effect of the filtering bags was a very interesting question.

He enquired whether there was intended to be any ballast at the bottom of the floating bath. With the straight vertical sides of the structure, there seemed some reason to fear the effect of a lurch over, as the water inside the bath was not confined in boxes or compartments, and consequently did not act as water ballast, but it was open at the surface, and therefore free to move, and if the bath lurched, the water in it would shift. It would not do he supposed to trust to the guides which moored the bath to the embankment, as it was necessary to avoid any strain on the guides, in order that the bath might be able to float freely in all positions.

Mr. H. Faija would be glad of some information as to the cost of constructing the bath. It seemed to him that to place a floating swimming bath in such an impure river and supply it with filtered water did away with the main object of such a bath, namely to secure the pleasure of bathing in a running stream, with a safe bottom, shelter from the weather, and conveniences for dressing.

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Unless therefore the cost of construction were less than that of erecting a bath on the land, there seemed to be nothing gained by the floating bath; and with the latter the cost of maintenance would be greater. If indeed the river water could be filtered for the bath at a lower cost than water could be supplied on land, the floating bath might be a success; but even then he did not see how it could answer commercially, when the great cost of maintenance was considered.

Mr. E. A. Cowper observed that the rent would be found to be much lower than that of a building on the land, as long as the conservators of the river allowed the floating bath to remain in its present position.

Mr. H. Woods considered the most important point in connection with the bath was the perfect or nearly perfect filtration given to the water. A considerable amount of ingenuity had been displayed in devising the filters described in the paper; and it appeared to him some improvement might be made if the filter last described (Fig. 15), consisting of a series of pairs of perforated discs covered with filter cloth, were employed as a final filter, after some other means had been used to take off the worst of the mud, which the unfiltered sample of water (No. 1) showed to be very bad indeed. Having himself been interested some years ago in the filtration of water for washing the casks at a brewery, he had employed for many years a plan which on the whole had been perfectly successful for filtering large quantities of water; and he thought it might be simplified and adapted to the filtration of water for large baths, or at all events for taking away a great portion of the impurities, before finally filtering the water through the disc filter shown in Fig. 15, which was certainly a very ingenious contrivance. In the plan that he had employed there were three cast-iron cylinders filled with sponge, the higher portion in each being of a coarse quality and the lower portion fine; and there was the means of pressing the sponge together, so as to increase as required the resistance to the passage of the water through the sponge. The

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water was pumped into the top of the first cylinder, and came out at the bottom tolerably clear. Previous to filtration it was nothing like so bad as the No. 1 sample exhibited of Thames water; in fact it was rare, except perhaps in some Lancashire districts, to find water so bad as that. The original water was perhaps about as bad as the sample exhibited of Thames water taken two days ago (No. 4); and after passing through the first vessel, which took off the coarser impurities, it was pumped through the second, from the bottom of which it came out as clear as the best sample exhibited of filtered water (No. 5). The quantity of water pumped through was that delivered by a 5-inch pump with 2 ft. stroke, making about 30 strokes per min. When after a time the water issuing from the second filter began to be somewhat less clear, and was no longer fit for use, the first filter was stopped, and the second was used in its stead for removing the larger quantity of deposit; and the third filter, which was quite fresh, was taken to finish the filtration. The first filter was then cleansed by pumping clean water through it from the bottom upwards, which issuing at the top carried away with it a large quantity of the mud, leaving the filter sufficiently clean to be used again in rotation. When any one of the filters had been thus used so many times that it would no longer yield water pure enough, the sponge was all taken out and washed. That plan had gone on in continuous operation from week to week with very fair results; and it had occurred to him therefore that in the bath now described some such vessels filled with sponge might be used for removing the coarser impurities, and that the disc filter (Fig. 15) might be kept for finishing the filtration of the water pumped into the bath.

Mr. S. C. HOMERSHAM said he had a very high opinion of sponge filters for a rough process of filtering, and had designed one a good many years ago for a brewery at St. Petersburg, which he believed had answered exceedingly well. The water used in the brewery was the water of the Neva, which at certain periods was mixed with very fine sand or silt; and for separating this, filtration through sponge was found to answer better than any other process that

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was tried. When it could be avoided however he preferred not to deal with water that required filtering, for he thought such water as a rule was not good for ordinary use, although it might be good enough to bathe in. At the Burton breweries that he had had to do with, he had found that the whole of the water used was spring water pumped from the red sandstone; and this was used not only for brewing, but also even for rinsing the casks containing the fine ale that was sent to India. The use of water from the river Trent was carefully avoided even for cleansing the casks, because if they were rinsed with river water it was found to set the ale fermenting in some unaccountable way; and at those breweries therefore it was essential to use spring water entirely free from all organic impurities.

Mr. H. WOODS said that at the brewery with which he had been connected at Burton, and at which he had employed the sponge filters, particular care was exercised about the water used for brewing, and not only for brewing but also for washing the casks; and for the latter purpose certainly no river water was used until it had been well purified by filtration, and was not less pure than the samples exhibited of filtered water for the bath. Spring water however was there in so great demand for brewing alone, that it was difficult to get a sufficient supply; and at those breweries they certainly could not afford a few years ago to abandon the use of river water for washing the casks. It was for this therefore that the sponge filters had been employed; and it was evident that they must to a certain extent have acted well, because in that particular case it would not have been worth while to filter at all, unless the filtration could be effected in a very thorough manner.

Mr. J. T. THORNEYCROFT observed that in the bottle exhibited of unfiltered Thames water, which had been shaken up a few minutes ago, the greater part of the mud was already settled, principally at the bottom. That was exactly what he had found took place in the Thames at high water and at low water, at which times the water settled itself and a great part of the impurity went down.

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This circumstance appeared to him not to have been taken notice of; and he suggested that if there were space to take advantage of it in the floating swimming bath, it might be a benefit for assisting very much in the filtration of the water.

Mr. A. Paget enquired whether any evidence had been obtained as to the amount of impurity in chemical solution in the water before and after filtration, because he presumed that filtration would remove nothing but solid matter in suspension. It would be interesting to know whether the filtered water was really chemically purer, and to what extent the impurity remained.

Mr. E. Easton mentioned that on three occasions he had used bag filters for water which contained extraordinarily finely divided particles of clay. One was at St. George's Hospital in London, where a bed of fine running sand had been hit upon in a well, and it was very difficult to get the sand out of the water; bag filters were there used with success, of somewhat the same description and thickness of material as the specimens exhibited from the bath. A much more difficult case had been at Maidstone, where a deep well sunk for the water works yielded water containing particles in such a finely divided state that it did not become clear even after standing three weeks to settle. It was filtered through bags with perfect success, two thicknesses of filtering material being employed, one of which was very like the bags shown from the bath, and the other was of a much finer quality; the filtering was done at the rate of from 40 to 60 gall. per min. from each bag of 4 ft. length and 3 ft. circumference. By an arrangement of cocks at the bottom of the bags, somewhat similar to that shown in the drawings, they were cleaned very readily at periodical intervals, duplicate bags being provided. These examples of the employment of bag filters on a small scale seemed to him to bear testimony to their practical utility for the filtration of water; and he saw no reason therefore why the same plan should not be successfully applied on a larger scale for the purpose proposed in the present paper. He enquired whether the samples exhibited of Thames water which had been taken

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eighteen months ago had been kept in the dark, or exposed to the light.

Mr. C. HAWKSLEY suggested that this mode of filtering through bag filters might possibly by a little modification be applied advantageously to the filtration of sewage sludge, by means of some such arrangement as the annular filter shown in Fig. 14. It appeared to him, from the information given in the paper respecting the rate of filtration with the bag filters, that the water was filtered through those filters at about eight times the speed at which it could be filtered through sand in the ordinary way, taking an equal area of surface in each case: though he was not aware whether the filtration was equally perfect.

The PRESIDENT hoped some remarks would be made upon the question raised in the paper, as to why it was that water filtered through the stone filter putrified in so short a time, while that filtered through a bag filter did not. This seemed rather a difficult point to explain. He enquired whether it had been attempted to filter any other substances, such as sugar syrup, by means of the various constructions of filters described in the paper.

Mr. T. HAWKSLEY observed that a misconception prevailed with regard to the operation of what was called filtration, which was generally supposed to produce something analogous to a chemical action upon the water. But in fact filtration proper, as distinguished from mere straining, was neither more nor less than the action of universal gravitation; and the curious way in which filtration was performed might be seen in the simple case of dirty water put into a bottle. It might naturally be supposed that gravitation would carry all the solid particles down to the bottom; but on a careful examination it would be found that a large number of the particles were attracted to the sides of the bottle and adhered to it in a sensible quantity, and that only a portion went to the bottom, though it might be a considerable proportion if the solid matter were very coarse and heavy. In his own experience as regarded the ordinary operation of

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filtration through sand, he had found that in that operation particles were taken out from the water which were far smaller than the apertures between the particles of sand; therefore it was not an operation of straining, because if it were so the smaller particles would pass through the larger holes, and would escape being caught; that however was not the case, but the contrary. The real action was that the facets of the sand attracted the particles of suspended matter from the water, and these became deposited and fixed upon the surface of the sand, by the operation of what might be called the attraction of aggregation; and inasmuch as the particles were suspended in a fluid which offered scarcely any resistance to their motion, they were very easily drawn out of it by the attraction. In Cavendish's well-known experiment, when two large globes of lead were freely suspended in proximity to each other, they coalesced; and it was exactly so in the case of the filtration of water, the suspended particles coalesced with the fixed particles, and the water was left clear.

Mr. Perrett, in reply to the enquiry about the rate of replenishing the water in the bath, said that, though in filling the bath 150,000 gall. could be delivered into it in five hours, it was not intended to renew the water continuously at that rate. No water would enter the filters from the river when the tide had fallen below the level of the inlet pipes to the filter tanks, the height of the orifices of these pipes being fixed so as to avoid drawing any water from the river for a certain period before and after extreme low tide, because at that time the river was more foul, and it was therefore desirable to avoid taking water from it then. During that time the water was drawn from the bath itself, and refiltered by being passed through the filters on the land side, and was then returned into the bath through the fountains, not perhaps so fresh as what came direct from the river, but at any rate refiltered and aerated; and in that way the water in the bath was renewed at a time when otherwise no supply could be obtained.

All the available width of the hull having been required for the bathing area itself, the dressing boxes had been arranged to project

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into the two recesses in the embankment, which could not otherwise be used. The number of separate dressing boxes was thus restricted to forty-six only, as those were all that could be got into the two spaces, and none could be allowed to project on the river side of the bath; but there was also the large public dressing room at one end, which could be fitted with separate boxes all round if necessary at any future time.

The heat of the exhaust steam from the engine was utilised for warming the bath, the power of the engine being assisted by the employment of a Morton's ejector-condenser, the whole of the water from which went into the bath; so that the bath water was warmed and an increase of power obtained at the same time.

With respect to the absence of ballast, he had looked upon the hull of the bath as being equivalent to a structure having no bottom; it was constructed of two parallel girders, and the fact of the bottom being added between them did not appear to him to affect the stability of the whole. If there were the possibility of a heavy continuous wind from the land side, lasting long enough to heel the bath over, there might be a liability of its filling and sinking. But there seemed no reason for anticipating such a possibility; and as the guides mooring the bath to the embankment had only 3 in. horizontal play in and out, they would check any excessive tendency to listing.

The cost of the bath, as it was not yet completed, could hardly be stated at present with any certainty. But one item, which in London especially could never be overlooked, was the site, the annual rent of which, had it been on land, would necessarily have been an exceedingly heavy sum, even if such a site could have been obtained at all; and that was one reason why a floating bath was so advantageous. The filtration of the river water would not amount to anything like the expense of a supply from the waterworks mains; and the river water was generally much warmer. The superstructure was no dearer than for a building on land; and though the hull was dearer, he did not think that, taking the structure altogether, it was any dearer than a similar kind of building on land would be, judging from the cost of existing land baths in London independently of their site.

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With regard to the suggestion that the water should be allowed to settle and so to clear itself partially before filtration, this was done at all waterworks where the water had to be filtered; and settling would no doubt be very beneficial in the case of the river water supplied to the bath, were it not that, on account of the time taken in settling, a much greater amount of room than was available would be required in order to obtain a sufficient supply of clear water. Additional space would indeed be wanted as large as the bath itself or twice the size, because in the settling it was only the top water that became clear, and it got darker and darker towards the bottom, so that probably not more than half could be drawn off for use, while the bottom portion would have to be pumped back into the river. Even the upper portion that was drawn off would still have to be filtered, because it did not settle so clear in a few hours as to do without filtration; and it had therefore been considered advisable to clear the water wholly by filtration, and not to use settling tanks. Another reason why settling tanks could not have been employed in this particular instance was that the slight motion which the bath would get in floating on the river would be sufficient to destroy the effect of settling.

In reference to the effect upon the water of filtering it through sand or through bags, he should imagine that both materials were about equally good; but he had found that the water from the stone filters putrified within a few weeks and became very offensive. How long the bag filters would last in the bath he did not know; in a sugar factory bags of the same material generally lasted about two years before requiring renewal. With sponge filters there was the disadvantage that in cleaning the sponge by a reverse current a quantity of clean water was consumed merely to cleanse the filter. It seemed preferable to be able to cleanse the filter with dirty water, of which there was an abundance; and this was done in the bag filters by letting a stream of unfiltered river water flow through the inside of the bag. He did not anticipate that any chemical impurities in the water would be removed by filtration through the bags; the only chemical change likely to occur would be the removal of some slight portion of ammonia by the aeration

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of the water in filtering and on its delivery into the bath through the fountains. A sample of the water had been submitted to chemical analysis, and a certificate had been received that it was quite fit for bathing, and that it contained less ammonia than previously to being filtered; but he had no information as to the amount of impurity in solution in the water. Practically all the solid matter was taken out of the water by the filtering bags, as after a sample had stood several days the sediment was barely perceptible. The samples exhibited of Thames water which had been taken eighteen months ago had been kept exposed to the light the whole time.

Having borrowed from the sugar manufacture the idea of filtering the water for the bath by means of the bag filters, he had in return made some experiments in the filtration of sugar by the different constructions of cloth filters shown in the drawings, with the view of endeavouring to improve the filtering process in sugar factories. With one of the ordinary bag filters used for filtering sugar, as shown in Fig. 11—the same that he had adopted for filtering the bath water,—he had found that each square foot of surface of the bag was capable of filtering a quantity of liquid containing about $1\frac{1}{2}$ lb. of sugar, before the bag required taking down and cleaning. The bags were usually hung up one day and taken down the next, but two hours was about the time during which they filtered in any useful quantity, the remainder of the time being principally expended in draining the scum in the bags With the stationary cylindrical filter shown in Fig. 13, in which the internal cylinder or drum of 2 ft. diameter was covered with filtering cloth of the same material as the bag filters, the quantity of liquid filtered per square foot of surface was four times as great as in the bag filters; the reason of the difference he did not know, unless it might possibly be that the cloth being here extended upon the drum, its whole surface was fully exposed to the liquid, while the bags were crumpled up inside the netting, so that perhaps all their surface did not come into play. But although the result was so satisfactory as regarded the filtration of the sugar, the cost of the apparatus was such that even this fourfold increase of efficiency was not sufficient to make it pay.

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The next plan, shown in Fig. 14, was a remarkable example of success in its way. When rotated so as to filter by centrifugal action, it was a failure; but it was afterwards tried for quiescent filtering, the liquid being placed in the annular bag formed by the hanging filter cloth, whereby a double extent of filtering surface was obtained in the height. The scum stuck on the inside of the annular bag, and on the completion of the filtration the cloth was turned inside out by the rising of the nut up the screwed shaft when the machine was put in motion, and the scum was thrown off by the centrifugal action. But the cost of an apparatus of this kind was too great to allow of waiting the time necessary to filter the last portion of the liquid, while on the other hand it would not do to throw away the unfiltered liquid; and the plan was a failure on that account.

The filter shown in Fig. 15, if it contained eight pairs of discs 6 ft. diameter, would filter in an hour a quantity of liquid containing about a ton of sugar; but the difficulty attending that plan in the case of sugar was that, in order to rotate the discs for throwing off the scum, the outside liquid would previously have to be drawn off, and in running off would inevitably carry away with it by its motion some of the scum already deposited on the discs. In filtering water, it was of course immaterial how much of the dirt deposited on the discs might be carried away in drawing the outside water off ready for cleansing the filter by rotation; but with sugar such a plan would not be admissible. This difficulty he was endeavouring to meet, though the mode of doing so was not yet perfected. The cleaning of the discs by the centrifugal action was perfectly successful, aided by the injection of a little steam or warm water inside the discs, though that was not always wanted; and with some such construction of filter as this an ample extent of surface could be obtained for the necessary quiescent filtration of sugar.

The President thought it would be a great boon if the efforts now being made by the author of the paper resulted in restoring to the river Thames the floating baths, one of which he (the President)

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remembered some forty years ago at Blackfriars Bridge. At that time the river was used for potable purposes; indeed the shipping in the Pool used to get from the Thames their store of water by means of barges, which were fitted with a species of filter; the river water was taken through the filter into a tank, from which it was pumped by hand into the ships' casks; he believed the water was afterwards said to get "sick" for a short time, and then it was all right for a very long voyage. For many years however the Thames had been looked upon as absolutely unfit not only for drinking but even for bathing purposes; if however the author of the paper were successful, as appeared likely to be the case, provided the specimen of filtered river water now exhibited were a sample in detail of what would be obtained in bulk, a great comfort would be restored to London. Looking at the excessive cost of land in any attractive neighbourhood such as that in which the bath was placed, there seemed ample reason to believe that the floating bath might be found, taking every circumstance into consideration, more economical than one on land, even if the structure were more expensive than an ordinary building, which however the author considered it would not be.

The bag filter, intended to be employed for filtering the river water for the bath, he had hitherto looked upon as an ingenious means of getting a large surface in a small space, a crumpled bag of 4 ft. circumference being put into a stocking which was only 1 ft. in circumference; but the results stated to have been obtained in the experiments made with the other forms of cloth filters described in the paper led him now to doubt whether after all the bag so crumpled up was as good a filter as it would be if the surface were all free and fully extended.

Mr. Perrett mentioned that he had tried an experiment with bags of 6 ft. circumference, put into the same stockings that were used for the 4 ft. bags, and they did not filter half as much again as the smaller bags, on account he presumed of being more crumpled up.

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The PRESIDENT observed, with regard to the disc filter shown in Fig. 15, he remembered that the engineer to whom he had been apprenticed, Mr. Hague, who had had a great deal to do with sugar machinery, had devised a filter exactly like it, but without the centrifugal cleaning, which had not occurred to him: in Hague's filter a number of discs, furnished with radii and covered with filter cloth above and below; were strung upon a vertical spindle of a cruciform section. The boss of each disc was a gunmetal collar having holes between the radii, which conveyed the filtered juice into the vertical channels of the cruciform spindle. Mr. Hague introduced these filters as an improvement on the bag filters, his object being to obtain a larger surface in a given space. But these disc filters had to be taken apart after a few hours and washed, and they would not be applicable therefore to the large requirements of a bath. He could not help thinking that the author's suggestion of centrifugal cleaning would render them perfectly suited for bath purposes, and also probably by future improvements for purposes like sugar filtration.

He had been much struck by the extremely clear and lucid explanation given by Mr. Hawksley of the theory of filtration and of the way in which filtration differed from mere straining; and he wished that Mr. Hawksley or some one else had solved the problem advanced in the paper, why water filtered through the stone filter behaved differently in respect to putrefaction from water filtered through a bag. That was a question which would remain for consideration, and perhaps some day a solution of it would be arrived at.

He moved a vote of thanks to Mr. Perrett for his paper, which was passed.

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The PRESIDENT proposed a vote of thanks, which was passed, to the Council of the Institution of Civil Engineers, for their kindness in having again accorded the use of their meeting and council rooms. He knew however he was speaking the views of that body when he said that nothing gave them more pleasure than to render to all cognate institutions meeting in London every facility which their house in Great George Street enabled them to afford.

The Meeting then terminated.

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SPECIAL MEETING
ON THE PATENT LAWS.

JUNE 1875.

A SPECIAL MEETING of the Members, called by requisition for the purpose of considering the Patents for Inventions Bill now before the House of Commons, and adopting resolutions and a petition to Parliament on the subject, was held at the Institution of Civil Engineers, London, on Monday, 28th June, 1875; FREDERICK J. BRAMWELL, Esq., F.R.S., President, in the Chair.

The notice convening the Meeting having been read,

The PRESIDENT said the business of the meeting was confined to the special subject for which it had been called. Some members of the Institution might be inclined to doubt whether it could ever be within the province of a scientific institution to hold meetings upon questions which were before the Houses of Parliament, and probably under ordinary circumstances such meetings would not be within their province; but there might be special circumstances which brought such questions within the scope of a scientific institution, and he believed those special circumstances existed in the present case. On the receipt of the requisition, it had to be ascertained whether the meeting could properly in accordance with the rules be called; and he thought the introductory paragraph of the rules showed it was the duty of the Council to comply with the requisition. That paragraph ran thus:—"This Institution has been formed to enable Mechanical Engineers, engaged in manufactories, railways, and other establishments, to meet and to correspond, and by a mutual interchange of ideas respecting improvements in the various branches of mechanical science to increase their information, and give an impulse to inventions likely to be useful to the members and to the community at large." It was thus seen that the question of invention came within the purview of the

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rules under which they acted. It was certain that there could be no body so much interested in inventions as was the body of mechanical engineers. Among them were to be found some of the greatest inventors of the present age, and among them also were to be found men who in their manufactures were day by day carrying out the result of the inventions of themselves or of others; and thus in the twofold capacity of inventors and of producers, the members of the Institution of Mechanical Engineers were deeply interested in invention. He believed it might be said the majority of the public had determined that invention went on as it had done in this country in consequence of having a good patent law, and that a good patent law was essential for the protection and for the increase of invention. That being so, any bill which was before Parliament that touched invention, touched mechanical engineers; and in that way therefore it seemed to him proper for this meeting to consider whether the bill before Parliament was one which should be passed in its present condition. The patent law of 1852 perhaps was not faultless, but it had worked very well. A Commission in 1865 and a Committee in 1871 sat to consider it. Both the Commission and the Committee determined that a patent law of some kind was needful, and they recommended certain legislation by way of improvement on the existing law. Nothing was done until the present year, when the Lord Chancellor brought in a bill, the one now before Parliament, in respect of which bill the present meeting was called.

It was to be regretted, he thought, that the patent laws were treated, for some reason or other, as a lawyer's question; but he did not see why they should be. Investigation had shown that there really was an extremely small amount of litigation connected with patents: indeed it had been found that there were only nine cases carried to a primary decision in the Courts of Law and of Equity in England, in any one year, in connection with patent matters; and when there was considered the enormous money interest involved in patent questions, it was at once seen that this proportion of litigation was something extremely small. However, for some reason, the patent laws had always been considered to be the

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property of lawyers, and not of manufacturers or other persons who really were interested in their working; and the bill as at present brought in was the product of a legal mind. In many respects it departed from the recommendations both of the Commission and the Committee; and therefore it might be taken that those two bodies, which had the advantage of calling before them extremely good evidence, and of investigating the matter with the greatest possible care, had, in consequence of the mode in which the present bill had been framed, without in many instances paying proper attention to the recommendations of those two bodies, to a large extent had their labours thrown away.

In presiding over the present meeting, it would be improper he thought for him to express any view at all, although he held very strong opinions on the patent laws; but although he thought it decorum in him to refrain from stating his own views on the subject, he thought he might with perfect propriety quote the opinion of an avowed opponent of the patent laws as to what the effect of the present bill would be when passed. Lord Granville, who announced that he was on principle an opponent of any protection for invention by patent laws, said in the present session:* "A careful consideration of the whole question has led me to the conclusion that patent laws are a mistake, and that their entire abolition would be not only for the benefit of the public at large, but for that of the class in whose interests they are usually advocated—I mean the inventors themselves." And then after a long argument his lordship concluded by saying, "I regret to think this cannot be a final settlement of this great question; but as I have admitted that the noble and learned lord would scarcely be supported by public opinion if he were now to propose the total abolition of the patent laws, I trust I shall not be deemed inconsistent if, having made a speech against those laws, I announce my intention of voting for the second reading of this bill." Lord Granville knowing that, at least in his judgment and in that of others, this bill in its present form was simply the beginning of the abolition of the patent laws.

* Hansard, Debates, 1875.

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Mr. E. A. Cowper moved the following resolution:—

That this meeting is decidedly of opinion that the Patents for Inventions Bill 1875, proposed by the Lord Chancellor, would be much worse in its operation than the Act of 1852, for the following reasons (amongst others), viz.:—

It would give unlimited power to the Lord Chancellor to stop all patents, as well as control the length of patents, and the terms on which they should be used, to a large extent:—

It would not appoint paid Commissioners to manage the office:—

It would abolish Provisional Specifications:—and

It would appoint irresponsible Examiners, who would have the power of reporting against the applications for patents, on grounds of which they frequently could not possibly judge.

He said that, although he was not one of the requisitionists for the calling of the meeting, the interests of manufacturers were so great, and the progress of commerce so important, that he did not think any apology was necessary for speaking in reference to a bill or an act which would affect manufacturers and commerce in the highest degree. He thought the patent laws had proved the greatest possible stimulus in this country to the progress of manufactures and inventions; they stimulated a man who had a simple idea to prosecute that idea to its completion, to make his models and machines, and to spend money and time upon his invention, which no other possible incentive could make him do. No expectation of an indefinite reward, or chance of getting some sort of premium, could instigate a man to prosecute his ideas and inventions so much as the patent laws, which simply gave him an exclusive use of his own invention for a very limited time, or a very limited share in its profits. He scarcely thought it necessary to go any further into the merits of the patent laws, because he thought it was generally agreed that the patent laws were most important and beneficial.

With regard to the bill which was to be brought before the House of Commons, he thought it was scarcely thoroughly understood, and he said so for this reason: he had read the reports of many of the deputations to the Lord Chancellor on the subject (all without effect he might say), and the heads of these deputations

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argued that there was a chance of patents being reduced from fourteen to seven years. He found there were in that bill ten distinct places where the Lord Chancellor had full power given to him, and he could refuse all patents, and there was no appeal from him. The way in which this was done appeared at first sight very plausible. The application for the patent was to be sent to an examiner, an irresponsible person appointed by the patent office, and he was to report adversely or in favour of the application. The Attorney General and the Solicitor General, having no time to examine fourteen patents and specifications per day, in addition to all their other work, would simply sign the paper and confirm the report of the examiner. The Lord Chancellor would then consider the application had been thoroughly examined by the examiner and approved by the law officers, and therefore sign the report, and the patent would be lost if the report were adverse. There would be not the least resource for the inventor, there was no appeal and no power for him to bring his case before the public, and in this way there would be an absolute destruction of the patent laws. There was no appeal from the Lord Chancellor, as he had power in the bill to make rules and regulations, and even power to settle any cases of dispute about licenses, and in that way he had really full power to destroy patents whenever he might think proper. Also power was given that any person might petition the Lord Chancellor against granting a patent, even a person totally uninterested in the matter.

There was another point to which a great deal of attention had been given by different bodies, and by the select committee of the House of Commons which sat upon the action of the patent law of 1852. It was enacted in that law that such person or persons as Her Majesty should choose to appoint should be Commissioners of Patents, together with the law officers; but there had never yet been appointed any person or persons under this act to manage the patent office. The Commissioners of Patents frequently did not meet for six or nine months—indeed they had gone 2½ years without meeting at all to manage the business, and it generally happened that they only met just to sign the report. Mr.

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Woodcroft, the clerk to the commissioners, was without any power to make any improvement or alteration, and had not even power to print the catalogue of the library, which had been lying in manuscript for the last five years, although it was admitted by the authorities of the British Museum that the Patent Office Library was one of the best technical scientific libraries in the country.

Another most important point was that the provisional specification would be entirely done away with by the new bill; and he thought all who had much to do with patents would consider the provisional specification a most useful arrangement, by means of which the patentee could secure himself, and have time to make a proper specification. If he were called on to make this at the moment that he made his invention, he could not specify it thoroughly or completely; and it could not then be of so much benefit to the public as it would be if he had time to specify more completely, and make further experiments. Therefore six months had hitherto been given for a complete specification after provisional protection was granted, to enable the inventor not only to save himself and prevent himself being robbed by others, but to make a full, true, and good specification, embracing the results of later experiments. Then again there were examiners to be appointed who would be entirely irresponsible, who would be something like the examiners of the United States patent office, and he thought the action of those examiners was not of a satisfactory character. There was a staff of about 400 persons in that patent office, and after an invention had been referred to the examiners they might report adversely, and it was then referred to other examiners, and then to the commissioners, and finally to the head commissioner; and sometimes, after the matter had gone through four or five stages at great expense and with great delay, everything was reversed by the head commissioner. He was acquainted with several striking examples of inventions having been examined and patented over and over again in the United States patent office during a period of twenty years.

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Mr. W. Smith seconded the resolution, and said he had found on enquiry respecting the bill now before Parliament that there had not been any meeting of the Commissioners to discuss what should and what should not be imported into the bill, and moreover that the Attorney General and the Solicitor General had not been consulted about its preparation, nor even Mr. Woodcroft, in whom was centered all the information in connection with the patent office and the operation of the patent law. It was not surprising therefore that a bill had been produced which could give no satisfaction except to the opponents of the patent laws. It was clear, he thought, that the measure had been framed for the purpose of entirely neutralising that which the title of the bill would appear to show it was intended to promote. The administration of the patent law was really placed solely and exclusively in the hands of the Lord Chancellor in as many as seventeen places in this bill; and the question of whether there should or should not be patents granted was dealt with by the bill in anticipation. This was utterly against public policy, and he considered the present high eminence of this country was to a great extent due to the wise provisions of the patent law; but this would be rendered practically useless for the protection of inventions, unless the progress of the present bill was stopped. The desirability of protecting inventors' rights was admitted he thought by the great majority, and that the patent law was a boon to the country and had materially benefited the prosperity of the manufacturing interests, and even the trade and commerce of the country. The advantages of the present provisional specification were he considered very important, for the great object was to get the complete specification put in the best possible shape as a guide for the inventors who might come after. In reference to the United States patent law, he thought the action and administration of it was the worst in the world.

There was another question that he thought could not receive too much attention: the granting of protection at a more reasonable price and for a more extended period than at present. He did not believe it was the interest of the Government or of public policy that inventors should be taxed to the extent they were at present, by

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being made to pay £25 for the first step, £50 at the end of three years, and £100 at the end of seven years. And with regard to the period of protection, fourteen years had been found too short a period by those experienced in the working out of inventions; and therefore instead of giving the power of shortening this to seven years, as proposed in the present bill, the period he considered should be extended to twenty-one years. Taking, as an example of the great inventions that had been made, Mr. Bessemer's process for the manufacture of steel,—during the first seven years he had to make a stand against objections on all sides, and it was not until after that period had passed that he began to realise anything. This was only one instance out of many of a similar kind.

In reference to any appointment of examiners, he thought that, rather than have such an examination as was proposed in the present bill, inventors generally would prefer to have none; and any question of an infringement was one that could easily be dealt with, where there was evidence of the prior existence of an invention in the records of the patent office. The best method, in the opinion of the majority of persons interested in patents, was, he believed, to have a larger number of libraries, and to supply a larger number of the patent books to those libraries, so as to facilitate examination by inventors, in order that everything which had been previously done and recorded might be easily ascertained; this it was considered would be much better than an expensive staff of examiners, who might not thoroughly understand the inventions submitted to them.

Mr. W. Carpmael remarked on the importance of invention to the progress and prosperity of the manufactures of this country. To bring an invention to a successful issue, not only was originality of mind required and great enterprise and perseverance, but also the expenditure of considerable and sometimes very large sums of money. Inventors would not and could not invent for fame alone; the requisite supply of capital to pay for experiments and for failures could not be obtained without the hope of a return. If the country desired that inventions should be made, the country must in some form pay for inventions, or the race of inventors

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would become extinct. Opinions very different from these were held in the House of Lords: in the debate upon the present bill the prevailing view appeared to be that patents were pernicious; that public opinion was not at present sufficiently educated to allow of their total abolition; but that the present bill was well calculated to pave the way for such a consummation. He considered that no bill introduced in such a spirit could be satisfactory to inventors and the country.

He believed that an efficient investigation of applications for patents was desirable, but he was not convinced that the examination contemplated in the bill was a fair bonâ fide examination; it appeared to be devised for the wholesale suppression of patents. In reference to examination, it appeared to him most desirable in the interests of the inventor that a patent should represent something more than the inventor's own assertion that he was entitled to levy a rate on certain manufactures. A patent at present represented nothing more than this; and so long as this was the case it was natural that patents should be looked upon with suspicion, and this suspicion detracted very seriously from the value of patent property. A patent ought to represent the opinion of an independent and competent authority that the inventor really was entitled to that which he claimed; but in the provisions of the present bill there was no security that the examiners would be either independent or competent. As to their independence, no information was given about the salaries it was intended to pay, or in other words about the standing of the men it was intended to appoint, and the appointments rested solely with the Lord Chancellor; and as to competence, it appeared from the bill that a legal education was considered a sufficient qualification in itself for an examiner of patents.

If there were doubt of the competence of the examiners, there was no doubt of the incompetence of the court of appeal. The cases for this court to decide would be, for example, whether one machine was substantially the same as another, or whether one chemical process depended upon the same reactions as another: questions these involving no law whatever, but frequently involving very difficult points of mechanical or chemical knowledge and judgment. The bill

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provided that questions of that sort should be sent to a Court of Equity. But such a court, having no technical or scientific knowledge, would have to procure that knowledge by examining scientific witnesses and experts,—a most expensive and unsatisfactory process. It was in effect an appeal backwards, from an examiner who might have some technical knowledge, to a court which certainly had none. If on the contrary there were placed on the Commission of Patents, say three men eminent in the applied sciences, and suitably paid (for their duties would not be less responsible than those of the judges of the superior courts), and if this court were strengthened by the addition of one lawyer, there would be provided as perfect a machinery for the control of the issue of patents as it appeared possible to devise. Then if in addition these Commissioners had referred to them for decision all questions respecting the infringement or validity of patents, there would be laid a thoroughly sound foundation; the superstructure need not differ much from that provided by the bill, though many improvements in detail were needed. What was really wanted was that the administration of the patent law, instead of being in the hands of lawyers, should be put in the hands of those who by their education and training were competent to deal with manufacturing and scientific subjects. Anything less than this, though no doubt it might suffice to palliate some of the existing evils, would fail to place the patent law on a satisfactory and secure basis.

Mr. F. W. Campin thought from his own observation there was a great feeling amongst inventors in favour of a proper system of examination; and he quite agreed that it was desirable to have such an examination as should point out to an inventor that he could not possibly obtain a valid patent by reason of want of novelty, or from any other cause preventing him from having a good right in the invention. Examination into the novelty of an invention must always be a matter of very considerable difficulty; and he felt clear that unless there was at the patent office, as the first step in the examination system, a supply of full and complete indexes, and the means for enabling examiners to go thoroughly into the different

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inventions already patented, the office of the examiners would be practically useless. It would be impossible for them to do the work without having all these means at hand; and it rather appeared to him that, if those means of investigation were placed at the service of inventors, they might really do for themselves the very thing which the expensive machinery of examiners was intended to effect.

In reference to the proposed abolition of the provisional specification, it had to be noticed that in the present bill provisional protection was not abolished, but it was proposed to be given on a complete specification; and a provision was added that did not previously exist, by which supplementary matter could be put into the full specification, and this altered a good deal the application of the bill as regarded the complete specification. Still however an inventor would have to lodge at the patent office what was supposed to be a complete specification; and would have to do that before he had an opportunity of properly going into the details of his invention, so that it would be a most imperfect document. It would be inferior he thought to the present provisional specification, which laid down the general features of the invention without going into details. The provisional specification and protection were of great importance to the working class of inventors, because they were not likely to be able to put their ideas into form at first, sufficiently to make anything like a document that would satisfy the requirements of the law; also because they would not be likely to have a complete specification drawn up without professional assistance, and would consequently require a considerable expense at the first start. During all the time of preparation they would be waiting for the protection that would enable them to negotiate with capitalists, or with any to whom they might require to resort for carrying out their invention. In most of the petitions to the House of Commons on the subject, the abolition of provisional protection was spoken of as a thing highly detrimental to that class of inventors, and it was represented also that this protection ought to be granted at a very cheap rate.

The resolution was passed.

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Mr. W. E. Newton moved the following resolution:—

That any preliminary examination of applications for letters patent which may be hereafter instituted should not extend beyond the questions whether the specifications are clear, and whether the invention is open to objection on the ground of want of novelty, regard being had to prior publications in the Patent Office.

That an adverse report should not disentitle an applicant to a patent.

That in lieu of the proposed publication of reports (which would in many instances operate unjustly), the applicant should merely be required to insert in his specification an acknowledgment of the existence of the prior matter found and pointed out by the Patent Office officials, with a clear statement of what he claims notwithstanding.

He thought there was no doubt that the present bill was really intended for the abolition of patents altogether, and that unless some very serious alterations were made in the bill it would have that effect; and it was therefore very necessary to consider what alterations were required. He quite agreed it would be better to retain provisional specifications, because, as had been pointed out, it gave the opportunity to a poor inventor to put down his ideas in a rough way, and to obtain protection, which enabled him to go to his employer or some other capitalist for the means of working out his invention. It was true that England was the only country in which provisional protection was given upon depositing a general description of an invention; and in all other countries it was necessary, before protection could be obtained, to give a detailed description, illustrated with drawings and sometimes with models, setting forth the whole nature and scope of the invention. But on the other hand, it had to be borne in mind that patents in the United States, France, and Belgium, were much less expensive than in this country. Also, in France, if anything had been omitted in the original specification, additions could be made from time to time during the whole period of a patent; and in the United States a patent could be "re-issued" as it was termed (by the original patent being delivered up if found defective in some points), and there could be included in the re-issue anything shown in the drawings that had not been properly described and claimed. Under those circumstances, it appeared to him that the position of England was quite different from that of other countries in dealing with the question of patents.

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In regard to examination on the application for patents, he had strongly objected to this, because he had seen the absurdity of it in the United States; the law there was as good as it could be, but its working was exceedingly bad. He had seen instances in which the same invention had been patented several times, notwithstanding the examinations which the applications were supposed to have gone through. He agreed that an examination of some kind would be of advantage to the patentee, and it would have the effect of relieving patent agents of a great responsibility. But it must be remembered that there were very different kinds of examinations, and in the present bill an examination was proposed extending to six points. First, whether the invention was a proper subject for a patent within the "statute of monopolies;" which might be a reasonable thing for enquiry by proper authorities. Secondly, whether the specification was sufficient, and properly described the nature of the invention, and in what manner it was to be performed; and that was also a reasonable enquiry. Thirdly, whether the invention was open to objection on the ground of want of novelty, so far as this could be ascertained by such examinations as were prescribed of former specifications and of other documents in the patent office; and if that were properly carried out it would no doubt be a great advantage to the inventor, because by filing his application, which was to cost only £5, he would be enabled to ascertain with a tolerable degree of certainty that his invention was really new, and that there was nothing in the patent office to detract from its novelty. The fourth point however was that the examiner was to declare whether the invention was in its nature wholly or mainly a combination of known machinery, substances, or processes; there did not appear to him to be any occasion for such an enquiry, as an invention might be a valuable one although merely a combination of things previously known. Then the next point for enquiry was whether—regard being had to the last-mentioned consideration, or because the invention was not of great importance or utility, or for any other reason—it was expedient that the duration of the patent, if granted, should be limited to seven years. In reference to this proposal, he was sure it would be generally agreed that, in

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ninety-nine cases out of every hundred, inventors did not realise anything like what they ought in the first seven years of a patent; and therefore to grant a patent for only seven years would be a delusion, because, although power was given to the Lord Chancellor, in another part of the bill, to extend the patent, this was to be entirely at his will, and the chance of its being extended would not be sufficient to enable an inventor to get capital advanced for working the patent towards the end of the seven years. The last point was that the irresponsible examiner was to determine whether, by reason of the frivolous character of the invention, it was worthy of a patent at all. Such a question was, he considered, entirely beyond the power of any examiner to decide, because it was well known that many inventions which might at first have been declared frivolous and of no great utility had ultimately turned out really good things. On consideration of the above points, he was decidedly of opinion that, if there were to be any preliminary examination, it should be confined to the first three points named, and the others should be entirely excluded. The meaning of the resolution which he had moved was simply that, supposing an inventor applied for a patent for improvements in a steam engine, and the examiner reported that another patent of forty years previous appeared to him to have the same object in view and to have a very great similarity, the inventor might reply that he considered the previous inventor might have had the same idea, but had not succeeded in carrying it out, and that no one else had done so but himself, and therefore he considered there must be something in his invention; but he would agree to state in his specification that he had had the prior invention before him, and also to point out the particulars in which his own invention differed, and what he claimed as his own invention.

Mr. W. Lloyd Wise seconded the resolution, and remarked, in reference to the first point in the proposed examination which had been referred to, that he considered the wording of the clause in the Lord Chancellor's bill was too comprehensive, and might include not only the question of novelty, but also that of utility, and

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consequently of practicability, so as really to involve the pre-settlement of those questions which were usually reserved for more mature consideration before another tribunal only in case of litigation; and it would be a great mistake to throw upon an inventor the expense of meeting all that in the first instance. Such an enquiry could never be conducted satisfactorily, and he thought the result would often be to give a false colouring to the value of a patent. The second point, whether the specification was sufficient, might very properly be examined within certain limits, such as had been pointed out by the Patent Law Committee, who had proposed that the examination should be as to whether the specification was sufficient in point of form, and accorded with the title and provisional specification. But if the entire question of the sufficiency of the specification were to be gone into, the examination would be utterly impracticable he considered, because it was impossible for any body of examiners in a large number of cases to decide whether a specification mentioned all the ingredients that were to be used for obtaining a certain result which was stated by the specification to be the object of the inventor; also it required close examination, and often many experiments, to make certain, even in the case of a mechanical invention, whether the several parts were properly arranged and adapted to fulfil their office. In reference to the third point of examination, whether the invention appeared open to objection on the ground of want of novelty, so far as this could be ascertained from the prescribed examination of former specifications and of other documents in the patent office, he thought such an examination was very desirable. At the present time an inventor seeking a patent was first told by his adviser to ascertain that he had not been anticipated; and on going to the patent office he was utterly at a loss to know where to finish his examination, or under what heads to search, because the indexes, though good so far as they went, were far from perfect; he had a laborious task, and had to give it up before ascertaining what really ought to be known for enabling his claims to be properly framed. But with proper indexes and a regular staff of examiners or examining clerks, the work would be apportioned to

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them according to the different classes; and they would become so well acquainted with their several departments as to be able to point out the rocks to intending patentees, and enable them to keep clear of these. If however it was further to be determined by the examination that the invention had a sufficient amount of novelty to entitle the applicant to a valid patent, then a question would be gone into which should be reserved for the consideration of a higher tribunal. The Lord Chancellor's court was the court of appeal provided by the bill, and the Lord Chancellor himself was to hear these cases, although that court was generally considered to be already overburdened with work. The fourth point of enquiry seemed to him quite unnecessary, because it was difficult to imagine an invention, that would sustain a patent, which could not be classed as a combination of known machinery, substances, or processes. It was stated in the bill that the examiner should report his opinion whether the applicant might be allowed a patent or not; the Commissioners were then to make public the application and specification, with the relative documents and reports, and the reports were to be annexed to and go with the specification. One of the recommendations made by a Committee of the Social Science Association some years ago was that there should be an examination as to novelty, but that the applicant should be allowed a patent, notwithstanding an adverse report from the examiners, on certain conditions, one of which was that the adverse report should be recorded and annexed to the specification. But it appeared to him the practical effect of such an adverse report might be very objectionable. He thought the Committee could not have taken into consideration what would be the practical effect of publishing an adverse report. Supposing the great invention of the Siemens regenerative furnace, the patent for which was refused in Prussia, had emanated from a poor man; and supposing a report had been annexed to the patent for that furnace, to the effect that in the judgment of the officials the patent though granted was not sound;—he asked whether there was anyone who in the teeth of such an adverse report would have taken part in providing the large amount of capital required to introduce such an invention. If

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such reports were to be published, he felt sure that nine-tenths of the inventions which, though at first sight appearing comparatively unimportant, turned out ultimately to be of immense practical value, would be stifled at the very outset. The proposal that, notwithstanding adverse opinions of examiners, patents should be allowed, had been influentially supported, and he thought it a good one, if taken with the proviso that the adverse opinions should not be published. The examination being one for novelty alone, if an acknowledgment of any prior matter was made in the specification, the public would be effectually informed as to the extent of the invention.

Mr. C. W. SIEMENS supported the resolution, and observed that the patent bill under discussion had done good in one respect, in showing to many somewhat impatient friends of the patent cause that there was a really valuable patent law in this country, which, though it might be susceptible of improvement in detail, contained important provisions that distinguished it from those of other countries. The opposition which had been raised to the provisions of the proposed bill had also shown so very plainly how difficult it would be to go on without patents, that it might be anticipated some other bill would be introduced at a future time which would not attempt to undermine the patent laws, but would be conceived with a view to improve them. In that case all friends of industrial progress would, he was sure, support the measure. The most difficult point for consideration was that of preliminary examinations; and looking to the working of the system in other countries, it was seen that in the United States it existed with a bias in favour of inventions, the legislature favoured the applicant, and if any abuses arose they were inherent in the system of examination combined with the power of rejection. In Prussia on the other hand there was a system of examination with a bias against the patent altogether. It appeared to him that under the provisions of the present bill the examinations would approach more nearly to those of Prussia; the Commissioners appointed would be instructed to seek for an excuse to refuse the application, rather than to try to modify

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the application in such a way as to give the applicant the benefit of a patent. The question of the best form of examination was involved in difficulty, and he must admit that he had not yet been able fully to satisfy himself about it. Examination was decidedly useful, if it stopped at the point where it gave the applicant information that was useful to him. In seeking a patent the applicant sometimes had an elaborate search made by his agent, which was naturally costly, and many an inventor would not be willing or able to incur the necessary expense of that examination. But the applicant had to pay a considerable sum of money to the patent office for procuring his patent; and it seemed very natural to propose to relieve him from the onus of having to make this search for himself, but to give him the information he desired for the fees he had to pay. If that plan were carried out, with the idea neither to baffle the applicant nor unduly to encourage him, but simply to give him such information as would enable him to adopt the correct course with regard to his invention, that would be an undoubted benefit. He suggested that it would therefore be sufficient for the examiners clearly to state what had been done and what had been proposed to be done, and so to warn the applicant what he had to avoid in his specification. There was not any occasion to go the length of endorsing a condemnation upon his patent, but simply to inform him of what was known and published and was therefore to be avoided, without adding any advice as to proceeding or not proceeding with the application. Some such medium course might probably be the means of meeting the difficulty, which was a real one.

Mr. J. M. Napier said he had been connected with patents for many years as a manufacturer and patentee, and had a strong feeling in favour of patents. The new bill that was under discussion appeared to him very unsatisfactory, and to a certain extent ignorantly framed. From his own experience he thought it was really necessary to have a provisional specification; in France there was not any, but there was something else in its place, and in his opinion the provisional specification was preferable. If there were

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not a provisional specification, it would be impossible, as it seemed to him, to commence operations, without running the risk of losing the time and money expended. He thought it undesirable in any way to limit and tie up the patentee, or on the other hand to patronise him; he required freedom, and ought to be left alone. For his own part, as a patentee who had experience with a considerable number of patents, he preferred to be left alone, and not to have his inventions submitted to an examiner; but if a patentee wished for the assistance of an examiner, he thought it should be supplied to him without extra charge, and then the matter would be in a right position. A patentee was naturally anxious to know whether there was any previous patent which he would infringe, so as to avoid taking out a patent that had been taken out before; he was anxious for safety, but at the present time could not even get safety although he spent much time and exertion in searching previous patents, as the means of search had, owing to the alterations made within the last few years in the arrangement of the catalogue, become most difficult and laborious; recent patents could not therefore be looked up without great loss of time and patience. This had occurred to himself: he had searched the earlier years, but could not complete his search into the specifications of patents of the last few years, one of which he afterwards found he was trenching upon, and had to relinquish what he had unfortunately patented as a new invention. The inventor had been extremely useful in this country, and the whole progress of the country in his opinion greatly depended upon the inventor. If the amount of mind embodied in print in the library of the patent office was considered, it would be found difficult to say how, but by means of a patent law, the extent of improvement and progress there indicated could have been brought about.

Mr. W. Smith suggested that the large surplus fund accumulated from patent fees, which was now reaching the colossal amount of a million sterling, might be well applied in reducing the charges upon inventors, such as by making the payment for a patent an annual charge, say £5 per year, and £5 on first application,

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somewhat on the same principle as the French mode of protecting inventions. Instead of paying a large staff of examiners, it would be a better use for the money accumulated to spend it in giving a larger supply of the valuable publications of the patent office, and easing the burden on inventors by taking off the enormous tax in the third and seventh years, and reducing the whole charge to a uniform moderate annual payment, and enabling an inventor to drop his patent in any one of the years of the whole period.

Mr. W. CARPMAEL remarked, in reference to the alleged abuses in the United States patent office, that these might be partly due to the circumstance that the appointments were political, which seemed necessarily to lead to abuses that would not exist in an application of the system in this country. In reference to the cost of a search, this must necessarily be expensive when conducted for a patentee by an agent, because when instructed to make a particular search he had to build up a scaffolding, so to speak, for the special purpose; but in the case of a search in a government department, there would be a standing scaffolding always available. As to the publication of an adverse report, that would no doubt under present arrangements injure the patent granted; but this was from the circumstance that the adverse report had to go before a court altogether destitute of scientific or technical knowledge. If however the appeal were from a court of examiners with a little technical knowledge to a court with superior technical knowledge, there would be no such harm in the adverse report.

Mr. W. LLOYD WISE observed that, if reports were published, these reports coming perhaps from examiners who had some peculiar fancy of their own would not always be such as could be desired, but would nevertheless convey opinions which in a commercial sense would carry great weight against the patentee, and so act injuriously and unfairly.

The resolution was then passed.

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Mr. R. H. Tweddell moved the following resolution :—

That inasmuch as the changes in the law proposed by the bill now before Parliament differ materially from the recommendations of the Royal Commission of 1865, and of the Select Committee of 1872, it is expedient that no legislation on the basis of the bill now before Parliament should take place without special reference to a Select Committee.

He thought that patentees required to be less legislated for, or, as had been remarked, to be left alone; and he certainly did not agree with those who thought it practicable for inventors to dispense with the services of patent agents or lawyers. He had himself some experience in bringing out novel inventions, some of which he had patented and others not; and in many instances he thought it was not necessary that an invention should be patented to be profitable to the inventor. There was one objection to the indiscriminate granting of patents: he referred to those for frivolous and trifling improvements, which only prevented others from carrying out ordinary combinations, which they themselves would never think of patenting, but which still brought in a considerable profit, although simply the results of applying an engineering education to the subject. He was quite sure that no verdict given by a board of examiners, such as the new bill contemplated, would ever give satisfaction. He did not think the House of Lords a competent body to legislate on patent matters.

With regard to patent laws in other countries, he thought those in this country as good, if not better, and specially suited to Englishmen, who much preferred managing their own business. He had taken out patents in the United States, France, and Belgium; in the two latter countries there was nothing to do but to ask for and receive a patent. In the United States the course of procedure was extremely long; and numerous details which would be included in a single patent in England had there to be all made the subjects of separate patents, so that in the end the cost of a patent was more, he believed, in the States than in this country. Nothing better could be wished for than to have the Patent Act of 1852 carried out in its integrity; and until this had been tried he could see no necessity for the present bill.

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Mr. D. Halpin seconded the resolution.

Mr. F. W. Campin remarked there was one point of a serious character in the present bill which required correction, with regard to foreign inventions. Colonial inventions were included in the bill with foreign inventions in such a manner, as he understood it, that if anyone went to India, and whilst there devised an invention and sent home to get a patent for it, the taking out a patent in India would subject him, upon his not keeping up that patent or upon its lapsing from any cause there, to the loss of the English patent also.

Mr. W. E. Newton said the point with regard to foreign patents was even stronger than had been named; for if anyone took out a patent both in England and in any foreign country, and afterwards sold the foreign patent, as was frequently done, then if the purchaser ever allowed that foreign patent to drop, the English patent was lost with it. In reference to the Act of 1852, it had to be noticed that powers were given in that Act for the appointment of paid Commissioners, who could have any number of assistant examiners they might desire for examining patents; but these powers had never yet been exercised.

Mr. W. Lloyd Wise remarked that he thought it a mistake to speak of patents granted for frivolous improvements as standing in the way of bonâ fide inventions; if they really stood in the way of such inventions they could not be correctly termed frivolous. He agreed in the desirability of carrying out in its integrity the Patent Act of 1852; and when before the Select Committee he had recommended that that act should be properly carried out, and had pointed out several improvements which might be effected in its working; those recommendations were widely approved at the time, and he thought attention might now be advantageously paid to them.

Mr. W. Smith called attention to the fact that the Act of 1852 had never been worked out, and use had not been made of all that

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was contemplated by it; power was given to the Commissioners to associate others with them, and there were a number of other useful powers that had never been carried out by the Commissioners nor put in force for the benefit of inventors.

The resolution was then passed.

Mr. W. SMITH moved the following resolution :—

That this meeting is of opinion that many of the provisions in the Lord Chancellor's bill are contrary to public policy, and an interference with the admitted rights of inventors and others connected with property in invention.

He observed that the resolution was simply a declaratory one, following out the results of the discussion of the subject.

Mr. W. E. NEWTON seconded the resolution, which was passed.

Mr. A. PAGET moved the following resolution :—

That a petition be presented to Parliament against the bill, embodying the views of the meeting; and that the President be authorised to sign the petition on behalf of the Institution of Mechanical Engineers.

He remarked that, although it was now generally anticipated the bill would not be proceeded with in the present session, it might be revived in the next session, unless strong efforts were made to oppose it. He believed that the Lord Chancellor had publicly stated that in his opinion patents were against public policy, and that it was desirable to abolish them; and it appeared that in seventeen places in this bill power was given to the Lord Chancellor to refuse the grant of a patent, but he thought the large majority of the educated classes in the country were in favour of patents. The high position this country occupied had been obtained by the development of manufactures and commerce, with which invention, taken in its broadest sense, had had much if not most to do. He was acquainted with an illustration of the practical advantage of patents, that had occurred in his own family, in the invention by one of his ancestors, two generations ago, of the first knitting machine moved by steam power. The patent laws were then extremely defective, and the invention was consequently not patented, but worked on the

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secret plan. Every man in the works was bound under a heavy penalty not to divulge anything connected with the invention, nor to work for any other master in the trade during the whole of his life, and the factory and all the men were rigidly watched. But it was found impossible to preserve the secret, and ultimately the invention became known to a foreigner and was patented by him, and a compromise was effected by which the manufacture was from that time carried on under a license purchased for a nominal amount from the patentee. The result was that, although the invention had been worked for twenty years previously on the secret system, the development of the manufacture during that period was only very limited; but from the time it could be worked openly under the protection of the patent law the development became so rapid that more had been since done in one year than had been done in all the previous twenty years. That showed the power and opportunity for the development and general use of new inventions, and the consequent benefit to the public at large, caused by patent laws when they were even moderately practicable and workable.

Mr. E. Field seconded the resolution, which was passed.

The President said that the bill had already passed the House of Lords, but, with the highest respect for that body, he did not think it a proper tribunal to be selected for the purpose of determining upon the policy of the patent law. Lord Somerset, who, having been at the head of the Admiralty, might have been expected to have a little respect for inventions, was very jocose on the subject of inventors, and said that an inventor came and made a screw wide at one end, and another afterwards made it narrow at that same end, which gave him the right to a patent, and this patent his lordship held up to ridicule. But why should this be? might it not have occurred to him, if he had taken the pains to consider it, that the whole difference between a good screw and a bad one lay in the form of it? It was not until after years of experiment that even a commercially successful propeller was obtained, and at the present

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day it was the disgrace of mechanics that a propeller was not yet devised which would utilise a greater percentage of power than was got out of the screw; and although this problem was so difficult a one that men like Froude, who were engaged in experimenting to seek the cause of the evil, had not as yet with all their ability solved the question, in the House of Lords it was thought to be a fit subject for joking when a man so altered the form of a screw as to convert it from a bad propeller into a good one. There was good ground for complaint, he thought, that the patent law was made the property of lawyers; that the bill had been framed by a lawyer without any consultation with those who did know something about the matter; and that it ignored many of the recommendations of the Commission of 1865 and the Committee of 1871-2. It might accord with those recommendations in certain particulars, but it failed to carry out some of them; and it had many clauses not suggested by either of those bodies,—clauses which were, he believed, in themselves most prejudicial. He was very glad that the opponents of the bill had had furnished to them the arguments which had been brought before this meeting, but trusted that they would not be wanted this session, and that the bill would be among those dropped. Nevertheless it might be revived next session, and then he hoped that the resolutions and deliberations of the present meeting would have their weight, or, if need be, that the members of the Mechanical Engineers' Institution would meet next session for the purpose of recording their protest once more against the passing of a bill so injurious as he firmly believed such a bill as this would be if it became law, not only to inventors but to the country itself.

The Meeting then terminated.

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PROCEEDINGS.

July 1875.

The Annual Meeting of the Members was held in the Town Hall, Manchester, on Tuesday, 27th July, 1875; Frederick J. Bramwell, Esq., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

William Henry Barlow, F.R.S., .	London.
Francis Berry, ...	Sowerby Bridge.
Thomas Broadbent, ...	Huddersfield.
Francisco Corrêa de Mesquita Cardozo,	Pernambuco.
Robert Nivin Cottrill, ...	Bolton.
William John Crossley, ...	Manchester.
William Eaves, ...	Sheffield.
Richard Hammersley Heenan, . .	Bhawulpoor.
H. C. Fleeming Jenkin, F.R.S., . .	Edinburgh.
George Hamilton Kenrick, . . .	Westbromwich.
Robert Maclagan, ...	Japan.
Alfred Marshall, ...	London.
James Matthews, ...	Bridgwater.
Thomas William Matthews, . . .	Manchester.
James Compton Merryweather, . .	London.
Arthur Rainford, ...	Calcutta.
Frederick William Stoker, . . .	Stockton-on-Tees.
Thomas Urquhart, ...	Russia.
John Webster, ...	Bahia.

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ASSOCIATE.

JOHN GREENWOOD, ...	Bradford.

GRADUATES.

MARTIN WILLIAM BROWN FFOLKES, .	Wisbeach.
HERBERT GURNEY SHEPPARD, . .	Birmingham.

The following paper, communicated through the President, was then read :—

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ON OTTO AND LANGEN'S ATMOSPHERIC GAS ENGINE, AND SOME OTHER GAS ENGINES.

BY MR. FRANCIS W. CROSSLEY, OF MANCHESTER.

The Otto and Langen Atmospheric Gas Engine is not only an exceedingly ingenious, but also a well tried and now largely used machine. The attempt to obtain a steady rotary motion from a series of either regularly or irregularly fired explosions—irregular in point of time—and to do this also in accordance with scientific principle, is no easy task; but here it has been accomplished.

The main characteristic of the engine is the "free piston"; the piston when impelled by the explosion rises freely upwards in the vertical cylinder, without at that moment actuating the machine, the motive power being obtained indirectly during the descent by atmospheric pressure acting on the upper side of the piston, in consequence of there being a partial vacuum below it, following the explosion. In the other type of gas engines, on the contrary, the force of the explosion is employed as the motive power, acting direct on the piston. Upon this principle were the two principal gas engines introduced in this country a couple of years previously to 1868, when the Otto and Langen engine appeared. They were both partially successful at the outset, but owing to numerous defects they never came into much use in this country. They were both very similar in appearance to the ordinary horizontal steam engine, and the principal difference between them was that the explosive charge was fired in the one engine by electricity and in the other by an arrangement of gas lights. A further difference was added when a jet or spray of water was admitted into the cylinder of the latter, which was evaporated there by the heat generated by the explosion, and somewhat aided in propelling the piston.

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The principle of both these gas engines however was entirely wrong in the writer's opinion, for the following reason. In both of them the explosion delivers its force upon a piston connected to a crank and flywheel, exactly as is done by steam in a steam engine; but therein lies the evil. Steam gives a steady and sustained thrust against the piston, and the gradual motion of the piston is suited to this; but it is quite otherwise with an explosion, as in that case the stress is intense but instantaneous only. The effect of delivering this sudden blow against a piston, connected rigidly with a heavy flywheel, is simply that, instead of the heat, set at liberty by the union of the oxygen and hydrogen in the explosion, being converted into mechanical motion, it remains in the form of heat, and has to be got rid of by a very large external supply of cold water, lest it should destroy the surfaces of the cylinder and piston, and even lead—as it has often done—to the buckling of the piston-rod when it has grown red-hot. In consequence the common steam-engine pistons of these engines, with their connecting-rods and cranks, will not, under any circumstances conceivable by the writer, enable them economically to utilise the suddenly generated and suddenly expiring force of an explosion. The blow given to the piston by the explosion is received by the heavy mass of the necessarily heavy flywheel, which cannot rapidly yield to it; and just as when a cannon ball strikes a massive target which it cannot carry along with it, a flash of fire is the result in which the energy of the shot disappears, so in these engines heat instead of motion is the result of releasing the stored energies of the gases, and in this case heat is not what is wanted.

The flame of carburetted hydrogen, when the combustion is perfect, is intensely hot; and when repeated discharges take place—say 150 a minute, as in the case of these horizontal engines—it is easy to see how much cold water must be circulated through the jacket of the cylinder in order to keep the temperature down to something below that at which oil oxidises, so as to prevent the destruction of the piston. It is possible however to keep the temperature sufficiently low even in these engines by supplying

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water enough; but it takes a great deal, and where constant working is required it often adds much to the cost of running, and all the heat taken up by the water is carried off without doing work.

There is yet another element of difficulty connected with these engines, and that is the deposit left by the gas after explosion. Their cylinders are very much smaller, say less than one fourth the volume of the Otto and Langen engine for the same power. This is in their favour in cost of construction, but it is a drawback in working. The difference in consumption of gas for the same power is found to be about as 1 to 6 in favour of the Otto and Langen engine, and as the cylinder in which this is burnt is also about 4 to 1 in volume, there is twenty-four times the space per unit of gas consumed in the Otto and Langen engine relatively to the others. There is consequently less liability to clog from deposit; and in order to become equally dirty the engine should require twenty-four times as many hours' work. There have been however some favourable reports of one of the horizontal engines in this particular, and perhaps the quality of the gas may often be such as to cause no difficulty from deposit even in them: though when the gas is dirty it is obvious the Otto and Langen engine has the advantage.

Some of the disadvantages accruing from using a common steam engine as a gas engine have now been shown; and this is practically what is done in the horizontal engines, excepting as regards the arrangements made for the firing of the charge and for the supply of the gas and air, in place of the valve for the passage of the steam. It has been pointed out that great waste of fuel, great generation of heat as a necessary consequence, a large supply of cold water as a further necessary consequence, and sometimes if not often a heavy deposit of carbon and tar in the cylinder and passages, are the results obtained from this principle of gas engine.

Now in the Otto and Langen engine, the idea of a "free piston" involves great constructive difficulty. The engine is really a gun, which stands vertically, with open mouth pointing upwards; the

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explosive compound of gas and air takes the place of the powder, and the piston represents the shot. The charge measured off is however not sufficient to drive the shot or piston out of the gun, and only to within an inch or two of its mouth.

The engine is shown in Figs. 1 to 3, Plates 23 to 25, which represent a $\frac{1}{2}$ H. P. engine. It is single-acting, the upper side of the piston B being continuously exposed to the pressure of the atmosphere through the open mouth of the cylinder C; and this arrangement greatly aids in keeping the cylinder cool. The piston-rod A is a rack, and it gears into a toothed wheel D on the main shaft E of the engine, which is mounted on the top of the cylinder. The length of the rack is about equal to twice the circumference of the wheel, so that the single-acting effect of the engine is very different from what it would be in a steam engine. The toothed wheel D however is not keyed fast upon the shaft E, but is attached to it by a friction clutch, which permits the rack to rise without moving the shaft at all, and connects them in the downstroke only. Thus the shock of the explosion is not sustained by the shaft, and the piston is able to move freely in the upstroke independently of it, being arrested only by the resistance of the atmosphere at the end of the upstroke.

The following is the series of operations in each stroke, commencing with the piston at the bottom, as shown in Fig. 1. First the piston is lifted through a space of about 1-11th of the length of stroke, as shown in Fig. 2, in order to draw in the charge of gas and air; and the power to effect this movement is obtained from the momentum of the flywheel. The charge is then fired by contact with a gas light, and the piston flies up freely to the top. As it ascends, the plenum caused by the explosion is changed to a partial vacuum, which reaches about 22 in. of mercury at the top of the stroke, and thus the motion of the piston is quickly reversed, and the downstroke is performed under a pressure of about 11 lb. per sq. in. derived from the atmosphere; this driving power is communicated through the rack and toothed wheel to the shaft. When the piston has reached within a short distance of the bottom, the vacuum, which has been gradually decreasing, is

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again changed to a plenum, and the weight of the piston and rack expels the burnt gases during the last few inches of the stroke, thus completing the cycle of operations.

The friction clutch, used to connect and disconnect the piston-rod rack with the driving shaft, is shown in Figs. 6 and 7, Plate 26. It consists of a pulley G keyed on the shaft E and surrounded by a ring D, on the interior of which are cut three inclined surfaces. On each of these inclined surfaces a set of live rollers is free to travel, and to press against a corresponding curved wedge I while the piston is descending; and at the same time the opposite side of the wedge, which is faced with leather, presses against the pulley G. While the piston is ascending, no pressure is put on these wedges by the ring, and hence in the upstroke the ring can freely revolve backwards upon its bearings on the shaft; but as soon as the downstroke commences, a firm hold of the shaft is immediately gained by the ring, and the shaft thereby becomes connected direct with the toothed wheel which gears with the piston-rod rack.

As by this means the piston is free to take any length of stroke within the limit of the cylinder, it is impossible to determine exactly at what moment it shall reach the bottom; and as the apparatus for lifting it to draw in the next charge is not required to move until the return of the piston, an intermittent motion is provided for lifting the piston, which is started at the right moment by a tappet fixed to the rack.

The mechanism consists of a pair of eccentrics H and K, Figs. 1 and 2, one of which H moves a lever L, which lifts the piston by means of a tappet M projecting on the side of the rack A; and the other eccentric K moves the slide-valve N of the engine. These eccentrics, which are made fast to each other, are carried loose upon an independent shaft T driven by spur wheels from the main shaft E of the engine; and they are started and stopped by an arrangement of ratchet-wheel R and catch P. The catch or paul P is carried by the eccentric H, and is made with a projecting tail opposite to the hook; and a stop S is arranged to strike the tail of

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the paul at a fixed point of its revolution, thus arresting it by throwing it out of gear with the ratchet-wheel R, which is keyed upon the shaft T. When the paul is in gear with the ratchet-wheel, it carries the eccentrics round with it; and when out of gear, all stop together. The stop S for disconnecting the paul is held up in position by a spring; but when the rack A descends to the bottom, the tappet M on the rack depresses the stop out of the way, and allows the paul to fall into gear with the ratchet-wheel. A revolution of the eccentrics now takes place, and when this is completed the stop arrests them until the next descent of the piston again effects their release.

But while the piston is lifted to draw in the charge, it is necessary to give the valve the power both of admitting the explosive mixture of gas and air, and also of applying the light to fire it when received by the cylinder. The valve for this purpose consists of a flat plate N, which moves between two faces attached to the cylinder base, the outer face being a moveable plate kept up to its place by springs. The valve is provided with ports, adjusted for proportioning the gas to the air so as to form the required compound; and it is further made with a small chamber, Fig. 2, having an opening both to the inside and to the outside; and an independent gas-pipe is carried into this chamber, so that a light may burn in it. Whilst the valve is at rest during the downstroke of the piston, the opening on the outside of the valve is exposed to the atmosphere, and close to it burns constantly a small gas-light, by which the gas fed into the chamber in the valve is ignited; but on motion being given to the valve, the communication of the chamber with the outside is cut off and is opened with the inside of the cylinder, and the flame that remains in the chamber explodes the charge. This is not effected until the gas and air supply are also cut off by the same movement of the valve.

The release of the exhaust or burnt gases is effected by the valve being provided with an independent exhaust port, which is open while the valve is at rest awaiting the descent of the piston, and so permits the escape to take place as soon as the vacuum has changed to a plenum.

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It is necessary however to provide a clack valve V in the exhaust pipe, closing inwards, as shown in Fig. 3, Plate 25, otherwise the atmosphere would enter the cylinder and destroy the vacuum, the exhaust port being open during the entire downstroke; and this leads to an interesting point in the action of the engine. It is clear that another explosion cannot take place until the piston has arrived at the bottom and given motion to the eccentrics, and so shifted the valve; but the piston cannot get to the bottom until the escape of the burnt gases is effected, and therefore by simply preventing this escape the interval between the explosions may be indefinitely prolonged, and thus the power and speed of the engine is controlled. This is done by arranging a common governor to press upon the clack valve V in the exhaust pipe, as shown in Fig. 3, and so delay the escape of the gases.

This is one of the most important features of the engine, and is the invention of Mr. Otto. To take an example of its effect, suppose an engine is employed in hoisting, and that the load demands the exertion of the full power to accomplish the work; in this case the governor will not press upon the exhaust valve at all, and explosions will take place as rapidly as possible—say at the rate of 30 per minute—whilst the load is being raised. Now suppose the load gets to the top, and all the work is suddenly thrown off, the effect of this will be to increase the speed of the engine sufficiently for causing the governor to close the exhaust valve; and until this is re-opened by the speed dropping, the engine will not make another stroke or explosion. In some of the best of these engines there will be a pause of one minute before this takes place; or in other words only 1-30th of the power of the engine is required to move itself whilst doing no work.

Perfect as the above method of governing the engine is in principle, it was found in practice to present a drawback. When the piston became leaky through wear, the exhaust was not obliged to escape only through the clack valve V; and thus by going out another way, evaded the action of the governor, and so "running away" of the engine was possible. The necessity for something

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better has now led to a great improvement in this detail, as shown in Figs. 4 and 5, Plate 26. Instead of preventing the piston from descending by closing the clack valve V, it is now allowed to descend, but its descent is not allowed to release the paul that puts the eccentrics in gear and moves the slide-valve N, unless the governor also permits it. The governor now controls a second stop, which keeps the paul from falling into gear with the ratchet-wheel and moving the eccentrics, not only until after the piston has descended to the bottom, but until the speed of the engine has dropped to the desired limit.

There are points of comparison between this gas engine and a steam engine in which the latter has the advantage. A steam engine does not necessarily make a noise in working; and the noise has hitherto proved to some extent an insurmountable difficulty with these gas engines, on account of the rapid and intermittent character of their movements. But on the other hand it is a very beautiful and advantageous feature in these gas engines that the governor is able, as described, to stop all motion of the parts, except the flywheel and shaft, as soon as the work is thrown off or less than full work is required. Instead of the piston continuing to rush to and fro while no useful duty is being done, as is the case with steam, it is here at perfect rest; and there is consequently economy both in fuel and wear and tear, as compared with steam.

The gas engine has other advantages, in the power of starting at a moment's notice, and starting too at full power: in the fact that while the engine is standing no fuel at all is burnt: and in the very trifling attendance required, which is very much less than with steam. There is no trouble with coals and ashes, nor in many cases is any water consumed. The engine not having any boiler, no boiler explosion can take place; and thus insurances are not affected by its use, or are only very rarely affected.

Lastly, the economy of fuel is perhaps the most important difference. Where gas can be had at low rates, the 1 H. P. engine will often run for 2*s*. 6*d*. or 3*s*. per week; it has not been known to exceed an average cost of 1*d*. per H. P. per hour, with gas at 4*s*.

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per 1000 cub. ft., and it is generally much below this consumption, though no doubt not exerting its full power continuously. Though 1*d.* cost of gas per H. P. per hour will not appear an economical consumption when compared with the value of say 2 lb. of coal per H. P. per hour, it has to be borne in mind that this comparison is made between the best and largest steam engines and the gas engine; whereas its practical opponents are the smallest and least perfect ones, in which the fuel burnt will probably be 15 or even 30 lb. of coal per indicated H. P. per hour. Also gas compared with coal is of course greatly more expensive in cost per heat unit. Taking all into consideration however, the commercial side of the question is entirely in favour of the gas engine in the matter of economy of fuel. When the fuel lost in raising steam and while a steam engine is standing, and the cost while running, are all taken into account, it is found that the gas engines have sometimes saved upwards of 15*s.* or even 20*s.* per week in fuel alone where they have replaced small steam engines, besides the saving in attendance, which is often nearly as much more.

But the most interesting question is the consideration of the engine from a purely scientific point of view. How many foot-lbs. are obtained on the break per heat unit supplied by the fuel? Here the best steam engines are surpassed by this gas engine.

Were pure hydrogen the fuel, instead of adulterated coal gas, no less than 2-5ths of the theoretical efficiency of the fuel might be realised on the break; coal gas however is less productive. Taking the proportion of coal gas to air for complete combustion as 1 vol. of gas to $6\frac{1}{2}$ vols. of air, and the theoretical efficiency of the gas as equal to 24,000 heat units per lb. weight consumed, one heat unit being equal to 772 ft.-lbs.,—and taking the density of the gas as 40 per cent. that of air, or 1 cub. ft. of gas = 0·03 lb. weight,—then the heat units supplied to the engine per minute are equivalent to 584,000 ft.-lbs., the consumption of gas being 1·05 cub. ft. per min.; and the return for this on the break is about 70,000 ft.-lbs., or 12 per cent.

Now to compare this with the best steam engine, allowing for air pumps and feed pumps and friction, is it not even too much to

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say that 2 lb. of coal will give under the most favourable conditions of a trial trip 1 H. P. per hour on the break? But taking it at that figure, and taking 1 lb. of coal to supply 15,224 heat units or 11,752,928 ft.-lbs., then $\frac{33,000 \times 60}{2} = 990,000$ ft.-lbs., or only $8\frac{1}{2}$ per cent. of the theoretical efficiency of the fuel: while the gas engine realises 12 per cent., or nearly $1\frac{1}{2}$ times the amount.

Some careful indicator diagrams lately taken from the gas engine, one of which is shown in Fig. 8, Plate 27, fully illustrate the fact that it is impossible to get a good result from the sudden force of an explosion except by some such means as a free piston. The very sudden and extreme rise in pressure at the moment of explosion is due simply to the expansion of the gases under the temperature of the flame. If this temperature be taken at 5000° Fahr., and divided by 520 for the rate of expansion from an initial temperature of about 60°, it gives an expansion of about 10 times; and as the gas compound occupied 1-11th of the cylinder at the moment of ignition, if it expands 10 times it gives very nearly the stroke actually taken by the piston. The 5000° is an assumption only, but seems to be confirmed by the amount of expansion which follows it. After the explosion the temperature falls almost instantaneously, as shown by the sudden drop of pressure in the diagram.

The driving pressure in the return or working stroke varies from 11 lb. per sq. in. at first, to nothing at about 4-5ths of the stroke, averaging 9 lb. during the time of action, or a mean of about 7 lb. per sq. in. effective pressure throughout the stroke. The steady and long sustained pressure during the return stroke, as shown by the diagram, is a proof of the continued fall in temperature even during the contraction of the gases, and is a testimony to the efficiency of this remarkable form of engine. Its spasmodic and intermittent movements are not what can at first sight prove palatable to engineering taste; but experience of its working shows that its faults lie almost wholly on the surface, consisting chiefly of noise, while its advantages are deeper seated, and make it in its very limited sphere a formidable rival of steam.

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The second indicator diagram, shown in Fig. 9, Plate 27, is taken from one of the other type of gas engines, using the explosive force of the gas as the direct driving power, and shows the inefficiency of that mode of employing gas. Nearly half the length of stroke is occupied in this engine by drawing in the charge of mixed gas and air, which is then exploded, and the pressure caused by the explosion propels the piston through the remainder of the stroke; the return stroke is an open exhaust into the atmosphere. The driving pressure indicated varies from 57 lb. per sq. in. at first, to nothing at the end of the stroke, averaging $13\frac{1}{2}$ lb. per sq. in. during the time of action, or a mean of about 6 lb. per sq. in. effective pressure throughout the stroke, which singularly coincides with the mean effective pressure in the Otto and Langen engine. In the horizontal engine 146 explosions, each burning about as much gas as one explosion in the 1 H. P. Otto and Langen engine, result in no better effect in driving power on the shaft than about 30 explosions in the latter engine.

Mr. E. A. Cowper said he had had an opportunity of seeing this gas engine at work; and in reference to the application of the explosion of gas for the production of power, he remembered an attempt was made many years ago to produce power, or rather to raise water, by the explosion of gas in an experimental engine, known as Brown's gas vacuum engine, in which the gas and air were mixed in a vessel having a loose cover; the cover was blown up by the explosion and then fell back into its place, and the vacuum produced was made to suck up water from a reservoir below, into the vessel, from which it was afterwards run out for use. That was an attempt to do away with the evils of the tar and dirt which resulted from the explosions of the gas in a closed vessel. A few explosions did not dirty a cylinder very much, but after working for some time there was an accumulation of condensed sulphurous acid and other substances, including tar, and these after some time

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generally caused the leakage of the piston, which was so exceedingly objectionable in an engine upon that principle. In the engine now described this difficulty seemed to have been got over to a considerable extent; but when the cylinder became worn, there would be an escape past the piston at the moment of the explosion. He had hoped that this leakage past the piston had been entirely overcome; he understood it had been overcome to a certain extent, and he should be glad to know how far.

This plan of gas engine had been spoken of as applicable only to produce a small amount of power. Now it was much more easy to work a small engine than a large one on such a plan, as the quantity of heat developed by the explosion of the gas was much greater in a large engine than in a small one. He should be glad to hear of further attempts and success with this engine constructed in a larger size; and to know what was the largest size yet made or in contemplation.

In reference to the mode of utilising the explosion of the gas, a larger space was evidently required in this engine for obtaining the power by means of the weight lifted by the explosion, than if the exploded gas were confined in a smaller space so as to drive by direct pressure. The exploded mixture of gas and air produced at the moment of explosion a pressure of about 150 lb. per sq. in. under favourable circumstances, but it was difficult in any engine to take full advantage of a sudden pressure of that amount. If it were possible to cut off the exploded gas neatly in the cylinder, and expand it thoroughly, a good indicator diagram would be obtained; but one of the chief difficulties was to explode the gas neatly and properly, and in order to produce a good diagram the stroke of the piston would have to be inconveniently long; besides which there were certain inconveniences connected with the application of the pressure in an efficient manner as a direct driving pressure. But with the vacuum principle the arrangement was greatly simplified; the piston made its upstroke freely, like a shot, and the power was obtained by the vacuum in the downstroke. He wished that more power could be obtained by that principle in a given space, so

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that the engine might be made more powerful and of larger size. The pressure of 7 lb. per sq. in. in the downstroke alone was equivalent to only $3\frac{1}{2}$ lb. in the double stroke, which was rather a small amount of pressure for a cylinder of the size shown; and he should be glad if an increased pressure could be obtained, so as to get more power from the same size of engine. Great credit was due for the very ingenious construction of the driving clutch, which he had no doubt was efficient in utilising the whole length of the stroke of the piston of a small engine, as long as it was kept in order; and the engine was altogether a highly ingenious arrangement.

Mr. A. PAGET considered the main principle of the engine was admirable for utilising the full effect of an explosion. The earlier gas engines had been as great anomalies as would be the use of a sledge-hammer with a cushion interposed between itself and the work on which it was employed; for in those engines the piston, piston-rod, connecting-rod, crank, and shaft, had each formed a cushion, which altogether absorbed and threw away the greater portion of the force of the explosion. The proper plan for utilising the power of an explosion was to store it up by some spring arrangement and give it out gradually; and in the engine now described this had been well carried out, so far as it went. He remembered seeing this engine in Paris in 1867, and its present appearance was certainly very similar to what it bore then, though some of the details had been modified since it was first brought out; but there were others which he thought still seemed capable of being modified with advantage.

He enquired what was the width of the driving clutch, and whether there was not a very considerable amount of wear upon the leather of the clutch; and also whether the leather as an elastic material interposed in the clutch might not cause a large amount of back-lash or slip before the clutch got a complete hold, and thus account for what was spoken of as a great annoyance,—the noise: and he enquired whether the amount of back-lash was not greater in this clutch than in many other forms of clutch in constant use.

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The clutch employed in wood-sawing machinery for giving the traverse to the wood seemed to be one among others which was attended with very little back-lash. When he had seen these gas engines working, he had found them making a great noise, much of which he considered was attributable to the back-lash; and he should be glad to know whether any other clutches had been tried in comparison with the one described in the paper, and if so what clutches, and what the result had been.

Another method that he had seen adopted in a single-acting engine, for obtaining circular motion when the power given out in the stroke was intermittent and irregular, consisted in making the piston-rod act upon a friction drum, so that in the effective stroke of the piston-rod it was pressed against the circumference of a pulley, and thus the piston-rod drove the pulley by friction as a leather belt would; but in the return stroke the piston-rod was withdrawn out of contact with the pulley, allowing the piston to make a free stroke without doing work. He thought he remembered seeing that plan in use in 1851, and it seemed to work successfully and to obviate noise, though it might be better for light work than for work so heavy as the work required of it in this engine.

With regard to the difficulty of getting rid of the heat in larger cylinders, this might be easily obviated by multiplying the number of the cylinders instead of increasing their size; and thus the heat would be got rid of sufficiently in each cylinder. The piston shown in the drawings seemed to be a solid and unnecessarily heavy block, and he suggested that the lighter this and the rack could be made, the less power would be absorbed in starting it into motion, and the less heat would also be stored in the cylinder below the piston.

As the speed must be to a certain degree irregular in consequence of the engine being only single-acting, he enquired whether any attempt had been made to obviate this objection by having two cylinders and two pistons, each working alternately, as such a plan seemed to present several advantages.

Mr. E. Reynolds said he had seen a good deal of the working of one of these engines during the last two years, and had been

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much pleased with the ingenious contrivance of the free piston acting only in the downstroke, and making the upstroke without transmitting any power. The starting of the engine was done instantly at any time by simply lighting the gas jet at the slide-valve of the cylinder, and giving the flywheel a turn or two by hand; he understood it was this that limited the size of the engine, because the attendant would not be able easily to pull round the flywheel of a larger engine. The evil arising from the heat developed in the cylinder by the explosions could not be very serious, as he had not heard of any trouble being experienced from that cause, nor had any repairs been required except a wheel on a second shaft. The cost of working a 1 H. P. engine he understood was only $\frac{3}{4}$*d.* per hour with gas at 3*s.* 1*d.* per 1000 cub. ft. As to the fact of the noise made in working, this certainly sounded unmechanical, and arose he believed from the clutch, which did not look very nice when at work, in consequence he considered of its being made of such a large diameter in proportion to the work it had to do; and this large and heavy clutch had to be set in motion suddenly by the explosion at each stroke. From numerous examples of circular clutches made with silent ratchets, there could be no difficulty he thought in making a clutch of only one-third or one-fourth the diameter, to transmit the same power.

Mr. W. H. MAW mentioned that trials had been made with one of Otto and Langen's gas engines in 1870 by M. Tresca at the Conservatoire des Arts et Métiers in Paris, for ascertaining the amount of power developed from explosive mixtures made with different proportions of gas and air, the horse power being measured by a friction break. The engine had a cylinder $8\frac{3}{4}$ in. diameter with a maximum stroke of 3 ft. $5\frac{5}{8}$ in., and the results stated to be obtained were—0·86 H. P. with a mixture of 1 gas to 27 air, and a consumption of 44·7 cub. ft. gas per H. P. per hour; 0·90 H. P. with 1 gas to 30 air, and 40·1 cub. ft. per H. P. per hour; 0·42 H. P. with 1 gas to 48 air, and 47·3 cub. ft. per H. P. per hour; and 0·43 H. P. with 1 gas to 54 air, and 46·4 cub. ft.

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per H. P. per hour. In each trial the consumption of gas included the small lighting jet used for firing the charges, which consumed about 2 cub. ft. of gas per hour.

With reference to the large proportions of air stated in these experiments, he thought the mode of determining the proportion of air and gas that was used appeared liable to error. The gas used by the engine was all passed through a meter, and the proportion of air was determined by assuming that the volume of air admitted was equal to the difference between the volume of gas as measured and the cylinder capacity up to the point of cut-off; but it appeared to him the gas would become expanded by contact with the hot cylinder surfaces, causing its volume in the cylinder to be greater than when passing the meter, and the volume of air admitted would consequently be proportionately less.

Mr. Jeremiah Head remarked that there could be no question as to the amount of ingenuity displayed in the construction of this gas engine, and the care bestowed upon its design; but one or two points occurred to him for enquiry in reference to its permanent working. The products of combustion from the explosions would contain, among other substances, sulphurous acid, ammonia, and carbonic acid; and these were in contact with both wrought-iron and cast-iron surfaces, and at a temperature which it had been suggested might be 5000° Fahr. at the commencement of the stroke, and was at any rate very high. He should be glad to know what was the practical effect of these highly heated gases upon the metallic surfaces: whether some chemical action did not take place, which would lead to the deterioration of the engine.

With regard to tar, it was quite possible that the gas of Manchester might be much better than that obtained elsewhere; but with the gas that he was practically acquainted with, the taps had to be eased once or twice every year, in consequence of their becoming stuck fast with tar. He had not heard how the difficulties which might arise from tar had been got over in the gas engine, and should be glad of some information on that subject.

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Mr. E. A. Cowper mentioned that in several attempts to work gas engines, and in some superheated steam engines, in order to keep the working part of the cylinder cool, it had been made with a slightly enlarged chamber at the end, beyond the bored portion, and the piston was made very deep, with a thick block upon it, which worked down into the end chamber. By that plan the explosion would take place in the end chamber; and though the heated products of the explosion must necessarily pass up into the working portion of the cylinder when the piston rose, they would only do so in a thin annular film, insufficient to heat the cylinder highly, and the greater part of the dust and dirt would be in the bottom chamber, below the working portion of the cylinder. That was a very good arrangement where there were any injurious products resulting from the explosion of gas, or where very highly superheated steam was used; and it was one which he thought might be carried out in such an engine as that now described.

With regard to the consumption of fuel, or the proportion utilised of the heat units, it had been estimated that 12 per cent. of the whole theoretical power was obtained in this gas engine, and $8\frac{1}{2}$ per cent. in the best steam engines burning at least 2 lb. of coal per H. P. per hour. As however steam engines were now made which were burning only 1·3 lb. of coal per H. P. per hour, this consumption would give a result of 13 per cent. as against 12 per cent. in the gas engine. He did not mean that so low a consumption as 1·3 lb. was a common thing; but there were large compound engines now working on that consumption.

Mr. E. H. Carbutt considered there were advantages in connection with this gas engine, if used for intermittent purposes. At Scarborough he had seen a pair of them at work in connection with a water-balance hoist, which was used for taking passengers up and down from the sea shore. The engines pumped water into a reservoir at the top of a hill, by which the hoist was worked when required. The passengers all required to descend to the sea shore at the same time of the day, and all wished to

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ascend about the same time also. The work was so intermittent that if the hoist were worked by steam it would be very much more expensive than with the gas engine, which could remain idle for hours without costing a penny.

Mr. J. Ramsbottom thought the best practical answer to the objections raised on the ground of the great amount of heat developed by the explosions in the cylinder of the gas engine was that if the mischievous effects were serious they would tell upon the working of the engine: just as in using ordinary gunpowder, when the temperature was too high the effect was seen in the gun after firing. He should be glad to know how far it was found from the actual state of the cylinder that the results of the explosions formed an objection to this construction of engine.

Any single-acting engine which admittedly gave out a working pressure of only 7 lb. per sq. in. in the single stroke, or $3\frac{1}{2}$ lb. in the double stroke, must necessarily be limited to very small sizes, and could not be put in competition with the steam engine for sizes much beyond those that had been mentioned. But it did not follow that an engine, ready at a moment's notice, even though of only 1 H. P., would not be useful for a great number of purposes, notwithstanding that its application was confined within these narrow limits. He thought there was great ingenuity displayed in its construction, but in the carrying out of some of the details of the engine it appeared to him there were objections which it was very desirable should be met by suitable modifications: in particular there was too much noise, and too much complication. But these objections being met, an economical and useful form of small engine was here presented, well worth the attention of mechanical engineers.

Mr. G. F. Deacon remarked that, in order to form a correct estimate of the real value of an engine of this description, it should be compared, not with engines using 2 or even 4 and 5 lb. of coal per H. P. per hour, but with that large class of small and admittedly wasteful engines used for intermittent work, such as

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hoisting goods at warehouses. Having had occasion a few years ago to investigate the comparative efficiency of both Lenoir and Hugon gas engines and of steam engines for such purposes, he had found that in most instances for intermittent work, taking the whole year's working, those gas engines were more economical than steam; but if the comparison were made for more continuous work the gas engines were inferior to steam in economy. In these estimates all charges, including attendance, were considered. If the efficiency of the gas engine now described were, as had been stated, about six times that of the Hugon and Lenoir engines, it must of necessity become in many situations a successful rival of small steam engines. The atmospheric gas engine had of course some disadvantages, one of which was that the small pressure per sq. in. on the piston and the single-acting principle necessarily involved a large cylinder; but it must be remembered that all boilers were got rid of.

Mr. W. Ford Smith thought there was some mistake in the case of this particular engine in estimating the effective pressure upon the piston at $3\frac{1}{2}$ lb. per sq. in., by halving the mean pressure of 7 lb. in the downstroke when actually doing work. Looking at the construction of the engine, it appeared that the time occupied for the upstroke was probably only one-twentieth or one-fortieth of that for the downstroke, owing to the explosion taking place instantaneously; and the power being given off only in the downstroke, it seemed to him that the effective pressure might fairly be taken as the full pressure on the piston while doing work, namely 7 lb. If the upstroke produced by the explosion occupied the same time as the downstroke, it would then be correct to consider that the effective pressure on the piston was reduced to $3\frac{1}{2}$ lb. per sq. in.

Mr. J. Ramsbottom observed that the piston had to travel through a double stroke in order to do the work corresponding to the pressure of 7 lb. per sq. in. existing in a single stroke alone; this was consequently equivalent to $3\frac{1}{2}$ lb. in the double stroke,

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however produced, irrespective of the length of time occupied by either half of the double stroke. A piston with $3\frac{1}{2}$ lb. pressure upon it in the double stroke would do the same work as the piston of this engine with 7 lb. pressure in the downstroke alone.

Mr. E. A. Cowper remarked that his object in suggesting that 7 lb. pressure per sq. in. in the single stroke of a gas engine was equivalent to $3\frac{1}{2}$ lb. in a double stroke was merely for the purpose of comparison of the size of the engine and the work done. The piston had of course to travel up the cylinder without doing work, because when the explosion took place the piston was thrown up as a shot, and that was a very advantageous mode of applying an explosive force. The piston by its momentum would rise higher than the point where the pressure equalled the weight of the piston, and the engine was thus an expansive one of the freest kind: a weight was thrown up to a certain height, and the fall of the weight was obtained through that height, together with the pressure due to the vacuum produced.

The mixture of gas and air that he had spoken of as producing a pressure of 150 lb. per sq. in. on exploding was in the proportion of 8 or 10 volumes of air to 1 of gas. Trials had been made of various mixtures, but 8 or 10 to 1 was found the best. A mixture of 20 to 1 would not explode, but a red-hot platinum wire put into it would be kept red-hot.

Mr. R. H. Tweddell thought the comparison of the gas engine with small steam engines used for working hoists in warehouses was the most favourable one which could be made for the gas engine, and that a comparison with small hydraulic engines worked by pressure from the special high-pressure water mains would not be so favourable for the gas engine. For engines of such small power however as the one under discussion, the question was not one so much of economy as of expediency and of having the engine handy and ready to go to work in a moment; this was not the case with the gas engine. It was stated in the paper that the engine started at once at full power; but it was necessary to pull the flywheel round

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by hand in order to start it, which took a certain amount of power, instead of simply moving a hand lever, as would have been the case with a hydraulic machine. The noise was very objectionable; and if it could not be avoided, it must be remembered that this defect was often urged against steam engines, but never against hydraulic motors. The gas engine he considered was likely to be of use in warehouses for small powers, or indeed wherever water pressure could not be obtained.

Mr. H. Simon suggested that if some information were given as to the extent to which these gas engines had been introduced it would be the best proof of the value in which they were held. So far as he knew, large numbers of the engines described in the paper were already in use abroad as well as in England.

Mr. W. W. Hulse mentioned that the gas engine was doing useful work at the Pomona Exhibition of machinery in Manchester, where the members would have the opportunity of seeing it at work on that afternoon.

Mr. C. Cochrane enquired whether in reboring the cylinders of the gas engines it had been found that the destructive action of the gases had produced any perceptible effects upon the metal, such as causing its surface to assume a porous character.

Mr. Crossley, in replying to the remarks which had been made, observed that this engine had the disadvantage of possessing defects which were more obvious at the first glance than its merits; and the questions as to the extent of its use and the wear and tear of the cylinder were most to the point. One of the cylinders had run for $4\frac{1}{2}$ years before reboring, and the piston had remained tight. One of the most successful applications of the engine was for hoisting, in which the work was of a highly intermittent character; and in such cases effective governing was most important. In the previous mode of governing, in which the burnt gases had to be retained in the bottom of the cylinder beneath the piston during the time that

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the engine paused, any leakage past the piston interfered with the action of the governor; but in the improved mode of governing, this objection was obviated, and the efficiency of the governor was not affected by leakage at the piston.

As to tar in the cylinder, there was no disadvantage from that cause, and the engine would run for a year without having the piston removed for cleaning the cylinder; this was in consequence of the large volume of the cylinder, compared with the amount of gas consumed in it. A small quantity of petroleum poured into the open top of the cylinder on stopping at night dissolved the tarry residuum; and it ran out through the exhaust port in the morning when the engine was started again, without any trouble whatever.

The limit of power was a question of great interest. The difficulty of making a machine work by explosion was well known, particularly when of large size. At present 3 H. P. was the largest of these engines that had been made, and it was not contemplated to make any larger size.

With regard to the difficulty met with of exploding the gas at times, this occurred no doubt in the horizontal direct-acting engines, where governing was effected by altering the proportions of the explosive mixture, so as to regulate the force of the explosions; whereas in the Otto and Langen engine the governor regulated the number of strokes per minute, by varying the interval between the strokes, without altering the proportions of the explosive mixture, which was consequently lighted easily under all circumstances. In one instance in which an Otto and Langen engine had started very badly, it had been found that there was a considerable quantity of air in the gas pipes; so that, instead of the engine being fed with pure gas and pure air which were then mixed in the proportion required, the proportion of air was too great, and the explosions were not made so well at the starting as if the engine had been fed with the proper mixture.

In calculating the efficiency of the engine, the number of heat units had been taken as those developed by an explosive mixture consisting of 1 vol. of gas to $6\frac{1}{2}$ vols. of air; whereas in the experiments that had been referred to the proportion had been

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1 to 8. Consequently the theoretical efficiency of the gas engine would be greater than that given in the paper.

With regard to the friction clutch, its width had been changed several times, and it was difficult to assign any definite dimensions. In the $\frac{1}{2}$ H. P. engine the width was now made $2\frac{1}{2}$ in. across the face of the leather. The wear of the leathers was not considerable, and generally one set of leathers would last for a year. They did not cost much, nor were they difficult to replace; the re-leathering of the three wedges in the clutch was only like renewing three boot-soles. The back-lash attributed to this clutch had no existence in reality: the wedges entirely obviated it even when worn. There were also no doubt other descriptions of clutch that would be applicable for the purpose required, but this on the whole was thought the best.

The recent modifications made in the construction of the engine had proved to be of great importance in reduction of wear and tear, and he did not see why these engines should not compare very favourably even in this respect with small steam engines; for large amounts of power it was not professed that they would be better. Their speed also was quite as regular.

The practical working was shown by the results obtained from one of these engines of 2 H. P. that was driving printing machinery in Birmingham, in comparison with two small steam engines of 2 H. P. each, which had previously been employed for the same purpose until replaced by the gas engine. The steam engines had certainly been highly inefficient, and he had received from the proprietor of the works the following statement of the cost of their working for one year in comparison with one year's cost of the gas engine:—

Steam Engines. Cost for the year 1872.	£	s.	d.	Gas Engine. Cost for the year 1874.	£	s.	d.
Coal . . .	76	0	2	Gas	14	9	5
Water . . .	4	8	7	Water . . .	2	2	0
Oil	1	5	0	Oil	2	10	0
Wages . . .	26	0	0	Wages . . .	5	6	0
Repairs . . .	2	0	0	Repairs . . .	12	0	0
Total . . .	£109	13	9	Total . . .	£36	7	5

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The amount of £12 for repairs in the account of the gas engine was in respect of the friction clutch, which as at first made was not strong enough, and the amount should be cut down for an average statement; but notwithstanding this it was seen that the balance in favour of the gas engine was £73 6*s.* 4*d.*, which was more than half the first cost of the engine.

Another comparison was afforded by a case where one of these gas engines had replaced a gas engine of the horizontal description, which had been in use in a large tailoring establishment in London for working a machine for cutting out cloth. The charge for gas with the previous engine, which had been doing less work, had been £3 per week; but with the Otto and Langen engine it was now only 7*s.* 10*d.* per week, or one-eighth of the former charge; the saving thus effected would in one year pay for replacing the previous engine.

The number of these engines that had now been turned out was 700 from his own works and 2000 by the German makers; but there were certain heavy restrictions on the use of steam engines in Germany, which did not exist in this country.

In reference to the action of the gases upon the metal of the cylinder, he had not examined the borings from the cylinder which had been rebored, but the surface had kept perfectly bright to the last, just like the surface of any vertical steam-engine cylinder. The cylinder had become rather enlarged at the bottom, and this had been an advantage rather than otherwise, because what was required was that the piston should be tight at the top of its stroke, so as to preserve the vacuum, any slight leakage at the moment of explosion being of much less importance, and the loss being partly compensated by an improved vacuum. Previous to the reboring of the cylinder, that engine had been running for several months with a very short stroke, owing to some defect in the coupling apparatus, so that the cylinder was worn more at the bottom than would have been the case with longer strokes of the piston. Another cause of the greater wear at the bottom of the cylinder might probably be, that in the previous mode of governing, which had been the one employed in that engine before

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the reboring of the cylinder, the piston had made a few little oscillations at the end of each downstroke, while resting upon the cushion of exhaust gases which were retained in the bottom of the cylinder until the exhaust valve was opened by the governor. But any wear that might have resulted from these oscillations was now obviated by the new mode of governing, in which the descent of the piston was no longer arrested by retention of the exhaust gases. How far the wear of the cylinder was really due to the oscillations or to chemical action he did not know: perhaps to both.

With regard to using a separate combustion chamber, that plan had been thought of; but it had been found best to explode the gas in the bottom of the cylinder itself. A separate combustion chamber would involve more expense, as well as a heavier piston, which would be a disadvantage. In one respect indeed a heavy piston had an advantage, because it flew up to the top rather more slowly than a lighter one, and thereby gave time for the gases to contract rather more under the cooling effect of the surrounding water jacket, and so to produce rather a better vacuum.

The PRESIDENT considered they were much indebted to the author of the paper for this description of an engine already largely in use and likely to be still more used, the merits of which had been brought forward in so unassuming a manner. For many purposes in small works for which it was desirable to lay on power, the water supplied by the water companies had been used when it was available for that purpose; and also for many years the gas supplied by the gas companies had afforded another convenient source of power. Gas had been employed both for firing steam boilers, and also for many years in gas engines proper. He could not help thinking the gas engine now described was one that promised better than any that had preceded it. When it could be stated that by the use of this engine a greater percentage of the heat residing in the gas was turned into useful effect than could be got from the best steam engine, the gas engine occupied a very good position indeed, and one which commanded respect. As regarded the various objections raised, a very effective answer to these was the small amount of repairs found in practice to be required.

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With respect to the cost of gas in this mode of application, as compared with water pressure from the town mains, he had made a calculation upon the basis of the water costing 6*d*. per 1000 gall. with a pressure of 40 lb. per sq. in.; a much higher pressure or a cheaper rate could not be relied upon in towns, and these might be taken as the conditions of an average supply. Under such circumstances the water for 1 H. P. per hour would cost 13*d*., while the gas was stated to cost only 1*d*. in one of these gas engines. Looking therefore at the employment of water or gas for the purpose of working engines of small power, the cost seemed to be largely in favour of gas.

In reference to M. Tresca's trials of explosive mixtures made with different proportions of gas and air, it had seemed to him that there must be some error in the results, judging from the experiments he had made in conjunction with Mr. Cowper, Dr. Frankland, and others; and he understood from Mr. Maw that the way in which the gas was conveyed and measured in those trials required correction or at all events verification.

He had been much struck with the plan of using a free piston as a means of utilising the force of an explosion; and that seemed to be at the root of the merit of this engine. The governor was also an exceedingly ingenious arrangement. If there were any practical details remaining that wanted improvement, no doubt those who had devoted so much attention to the subject and had brought the engine into its present state were competent to exercise further ingenuity in making additional improvements.

He proposed a vote of thanks to Mr. Crossley for his paper, which was passed.

The following paper was then read:—

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ON DIRECT-ACTING WINDING ENGINES FOR MINES.

By Mr. GEORGE H. DAGLISH, of St. Helen's.

In treating of this important subject the writer will refer to the principal types of Direct-Acting Winding Engines at present in work in the different coal-mining districts of this country. He is indebted to many friends for the data supplied, which he trusts may prove useful by furnishing the means of comparing the various usages and results in the different districts.

In Figs. 1 and 2, Plates 28 and 29, is shown a Single-Cylinder Vertical Winding Engine, having double-beat gunmetal valves and seats, with parallel motion and tappet valve-motion. A number of winding engines have been constructed of this type, of which one of the earliest has been at work over twenty-six years, having a cylinder 34 in. diameter and 5 ft. stroke, and a pair of flat winding drums D D, 9 ft. diameter. This engine winds coal from a shaft 10 ft. diameter and a depth of 450 yards in 55 seconds, or at the rate of 16 miles per hour; the time of banking is 30 seconds. The ropes used are flat, made of steel, and last about eighteen months. The engine winds four tubs at a time, each weighing 1¾ cwt., and containing 6¼ cwt. of coal, making 32 cwt. for the four. The cage and chains, which are of iron, weigh together 30 cwt. and the flat rope weighs 50 cwt. The total quantity of coal raised in 10 hours work is 250 tons, being at the rate of 25 tons per hour from the depth of 450 yards, or 112 tons per hour per 100 yards depth. The conductors are of iron. The boiler pressure is 45 lb. per sq. in. The repairs to this engine have been very few indeed, a new piston and a crank-pin having been the only renewals since the engine was started; and it has worked night and day since its erection in 1848. Another similar engine has been at work between twenty and thirty years, and in the shape of repairs has had only a new piston and crank-pin.

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A Single-Cylinder Vertical High-pressure Winding Engine of similar construction, which has been at work about seventeen years, has a cylinder 30 in. diameter and 5 ft. stroke, with parallel motion, and double-beat gunmetal valves worked by two tappet-rods T T, Fig. 2, one for each direction of winding. The boiler pressure is 50 lb. per sq. in.; and a cast-iron feed-water heater H is attached to the engine. The winding drums are flat, 9 ft. diameter. The pit shaft is 11 ft. diameter and 212 yards depth. The time of winding is about 35 seconds, and of banking 20 seconds, the average speed in the shaft being about 12 miles per hour. The rope is flat and of steel, weighing about 28 cwt., and it lasts from ten to fourteen months. The tubs are of wood, and four of them are raised at each winding; each weighs 4 cwt. and contains 8 cwt. of coal, making 32 cwt. of coal at each winding. The cage and chains weigh about 20 cwt. The engine winds about 520 tons of coal in 10 hours time, being at the rate of 52 tons per hour, or 110 tons per hour per 100 yards depth. The conductors are of iron. In consequence of the boilers driving this engine being pretty well worn out, it has been considered advisable to reduce the steam pressure upon them to 40 lb. per sq. in.; and this has been effected by putting in a new steam cylinder of 32 in. diameter, so as keep about the same power of the engine.

In Fig. 3, Plate 30, is shown a Coupled pair of Vertical Winding Engines erected some twelve years ago, having cylinders 24 in. diameter and 5 ft. stroke, and working with a boiler pressure of 40 lb. per sq. in.; the valves are slide-valves with Bristol's antifriction rollers, and are worked by a link motion. The winding drum is of internal conical form, $11\frac{1}{2}$ to 13 ft. diameter. The depth of the pit is 260 yards, and the winding is done in 35 seconds, or at the rate of 15 miles per hour. The ropes are round and of charcoal iron, and last twelve months in the wet pit, and eighteen months in the dry pit. The weight of the cage and chain is 20 cwt. The tubs, four in number, each weigh 3 cwt. and hold 7 cwt. of coal, making 28 cwt. of coal at each load; and the number of windings in 10 hours is 480, equal to 672 tons of coal, or at the rate of 67 tons per hour, or 174 tons per hour per 100 yards depth.

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Up to 1850 the direct-acting steam winding engines used in Lancashire or the neighbourhood of St. Helen's were principally beam engines or vertical engines. About 1851 the Horizontal Single-Cylinder High-pressure Winding Engine was introduced by the writer's firm, and several such engines were put to work at different collieries. At that time great prejudice existed against the horizontal engines, in consequence of the prevailing idea that the cylinders would become oval by the weight of the piston; and this must be considered the reason why the piston-rods were carried through the back cover of the cylinders, and a slide or shoe attached to them for taking the weight of the piston off the bottom of the cylinder.

Amongst a number of engines of this class may be mentioned one that is shown in Figs. 4 and 5, Plates 31 and 32, having a cylinder 36 in. diameter and 5 ft. stroke, with double-beat gunmetal valves worked by a loose eccentric; in Fig. 6 is shown a transverse section of the cylinder and valves. The drum D is flat, 10 ft. diameter, and on the drum shaft is a flywheel 20 ft. diameter, which is used for the break, Fig. 4. The back piston-rod was originally used for a feed pump P, but for the last five years the engine has had no back piston-rod. This engine has been at work night and day for the last twenty-two years at the Rose Bridge Colliery near Wigan, and has required very slight repairs indeed; the writer believes it was the first winding engine of the horizontal type, and the largest size of its class when first erected. The pressure of steam in the boilers is 40 lb. per sq. in. The pit shaft is 11 ft. diameter and 290 yards deep, fitted with iron conductors. The winding takes 35 to 40 seconds, giving a speed of from 17 to 15 miles per hour in the shaft. The rope is flat and of iron, weighing about 35 cwt., and it requires renewing about every twenty-four months. The number of tubs raised at each winding is four, each weighing 3 cwt. and containing 8 cwt. of coal, or 32 cwt. gross load of coal. The weight of the cage, which is of steel, is 28 cwt., with the chains. The total weight of coal raised in 10 hours is 800 tons, being at the rate of 80 tons per hour, or 232 tons per hour per 100 yards depth.

A Coupled pair of Horizontal High-pressure Winding Engines similar to that shown in Figs. 4 and 5 was erected in 1860 at the

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Rose Bridge Colliery, having cylinders 36 in. diameter and 6 ft. stroke, with double-beat gunmetal valves. Steam was supplied by eight egg-ended boilers, $5\frac{1}{2}$ ft. diameter and 36 ft. long, working at 45 to 50 lb. pressure per sq. in. Up to 1870 these engines wound from a shaft 16 ft. diameter and 605 yards deep. The ropes were made of steel, and were flat and taper, each weighing 57 cwt. total, and 48 cwt. in the pit; they had to be renewed about every eighteen months. The number of tubs raised at a winding was four; they were of wood, weighing 12 cwt. each, and containing $8\frac{1}{2}$ cwt. of coal, making 34 cwt. of coal raised at each winding; the cage and chains weighed 30 cwt. The number of windings in 10 hours was 500, raising 850 tons of coal per day, or at the rate of 85 tons per hour, or 514 tons per hour per 100 yards depth. The time occupied in each winding was 48 seconds, giving an average speed of 26 miles per hour in the shaft; the time of banking was 27 seconds. The winding drum was flat, 20 ft. diameter at starting, and $23\frac{1}{2}$ ft. diameter with all the rope on. The conductors in the pit were iron wire ropes with a steel stranded core.

In consequence of the seams at this colliery being worked out in 1870 at the shallower depth of 605 yards, these engines were then called upon to wind from a depth of 806 yards; and it was accordingly found requisite by Mr. John Bryham, the engineer and manager of the colliery, to increase the winding drum to 24 ft. 4 in. diameter, and 28 ft. diameter with all the rope on. The ropes now in use are flat and taper, made of steel, and each weighs 65 cwt. total, and 57 cwt. in the pit, and lasts eighteen months. Four tubs are brought up at each winding, each weighing $3\frac{1}{4}$ cwt. and containing $7\frac{1}{2}$ cwt. of coal, or 30 cwt. of coal altogether; the cage and chains weigh 30 cwt. The number of windings in 10 hours is 450, equal to 675 tons of coal, or 67 tons per hour, or at the rate of 544 tons per hour per 100 yards depth. The time taken in each winding is 55 seconds, giving an average speed of 30 miles per hour in the shaft; the time of banking is 27 seconds. The conductors are iron wire ropes $1\frac{7}{16}$ in. diameter with steel stranded core.

As it was considered advisable not to subject the present boilers to a higher pressure than 60 to 65 lb. per sq. in.,

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the back piston-rods were taken away, and the result has been that 4 to 5 lb. per sq. in. pressure of steam has been saved, while the piston rings, which are of cast iron, have been found to last eighteen months. The cylinders have never been bored or otherwise touched since they were erected, and it is considered the repairs have been less since the back piston-rods were taken away. Looking at the fact that these engines are now running at the maximum rate of 60 miles per hour in the pit, and with a maximum piston speed of 700 ft. per min., the writer considers this severe test sufficient to answer all objections to the abandonment of the back piston-rods and slides, and he consequently recommends that no slides should be used.

In Fig. 7, Plate 33, is shown a Coupled pair of Horizontal Winding Engines with 30 in. cylinders and 5 ft. stroke, fitted with an internal conical winding drum of 16 to 24 ft. diameter.

In Figs. 8 and 9, Plates 34 and 35, is shown one of the most modern style of Coupled Horizontal Winding Engines, having cylinders 36 in. diameter and 6 ft. stroke, and fitted with an external conical winding drum of 19 to 30½ ft. diameter, which is shown in section in Fig. 10, Plate 36. These engines are working at the Pemberton Colliery near Wigan, and wind from a depth of 638 yards in 55 seconds, giving an average speed of 24 miles per hour; the time of banking is 35 seconds. The cage is of steel, and with the chains weighs 29 cwt. It holds six steel tubs, weighing together 18¾ cwt. and raising 46 cwt. of coal at each winding. The winding is done at the rate of 92 tons of coal per hour, or 587 tons per hour per 100 yards depth. The ropes are of steel, tapering from 1½ to 1¼ in. diameter and each weighing 59 cwt.; they have now been in work from September 1871, and are not much worn. The pit is 16 ft. diameter, and the conductors are iron T rails weighing 42 lb. per yard. The drum makes 22 revolutions in each winding, and the steam is shut off from the engines at 2½ to 3 revolutions before stopping, or 80 to 90 yards from the top of the pit. The pressure of steam at the engines is 53 lb. per sq. in. The several handles for controlling the working of the engines are all brought together to the same place within convenient reach of the engineman, as shown

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in the plan, Fig. 9: S is the handle controlling the steam stop-valves V; and R is the reversing lever of the link motion; F is the foot lever for applying the break, which acts upon the centre portion D of the winding drum; and B is the handle for applying the steam gear A to work the break. The whole of the head-gear framing and heapstead is of iron, and the roofing over the stage is of galvanized iron. The arrangements enable twelve railway trucks to be loaded at a time, namely six with best coal, two with nuts, and four with slack; the level of the truck rails is 23½ ft. above the pit mouth. The head-gear pulleys are 18 ft. diameter and centered 45 ft. above the pit mouth.

Consumption of fuel seems in the writer's experience not to have been taken account of in colliery engines, and he has never yet been able to arrive at the quantity of coal consumed by a colliery winding engine, the general excuse being that the coal used at collieries was unfit for sale, and therefore it did not matter what quantity was burned.

From the Tables appended it will be seen that the condensing engine has very seldom been applied to the winding of coal; but with the greatly extended scale of mining operations at the present day it is worth consideration whether the more general adoption of the condensing principle would not be beneficial, where a sufficient supply of pure water can be obtained. Where this is the case, the existing high-pressure winding engines should have a separate condensing apparatus attached, with air-pumps worked by a donkey engine independent of the main engines, and under the control of the engineman, who would thus be able at all times to have the vacuum available for immediate use.

Counterbalancing.—In winding with drums of equal diameters up vertical coal-pit shafts, the actual working strain upon the engines is much greater at the commencement of the winding than at the finishing, in consequence of the weight of the rope in the shaft. For example, in the case of a shaft 806 yards deep, with a flat rope weighing 57 cwt., and cage and tubs weighing 43 cwt. and

raising 30 cwt. of coal, the load at the commencement of the winding is 130 cwt., less 43 cwt. on the descending rope, giving 87 cwt. net load upon the engine; and by the time the ascending load reaches the bank the respective weights will be 73 cwt. at the top of the pit and 100 cwt. at the bottom, or 27 cwt. acting to drag the engine forwards. Thus the power that has to be exerted during the winding of the first portion of each lift greatly exceeds that required to raise the coal alone; and at the end of the winding the engine has actually to exert a certain amount of power to retard the machinery, inasmuch as the weight of the empty descending cage with its long and heavy rope then exceeds that of the ascending loaded cage with its short length of rope. The different modes of counterbalancing such engines consist in the use of conical drums, levers, and chains.

Conical Drum.—The spiral or conical winding drum the writer believes was first introduced and adopted in Wales. In the Wigan district the first conical drum was started and set to work some fourteen years ago, and worked until 1872, when in consequence of an accident with a winding drum at another pit belonging to the same proprietors, this conical drum was altered, and a flat drum substituted for it. Whilst in use the conical drum was worked by a pair of 24 in. horizontal engines with 5 ft. stroke and 45 lb. steam in the boilers. The drum was of the shape shown in the diagram, Fig. 11, Plate 36, having a lagging of wood; it was 13 ft. diameter in the smallest diameter of the conical portion, and 20 ft. in the largest diameter and in the flat portion; it made 22 revolutions in winding, 11 laps being on the cone and 11 on the flat. It wound from a depth of 414 yards in 60 seconds, giving an average speed of 14 miles per hour. The ropes were of steel, 1 in. diameter, each weighing 20 cwt., and lasted two years. The cage with chains weighed 25 cwt., and held four tubs weighing 2½ cwt. each and containing 6½ cwt. of coal, 26 cwt. of coal being raised at each winding; the pit was 12 ft. diameter. The winding was done at the rate of 62 tons of coal per hour, or 257 tons per hour per 100 yards depth.

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The conical drum shown in the diagram, Fig. 12, Plate 36, of 19 ft. and 30 ft. diameter, was erected in 1863, and had a lagging of wood, in which the grooves for the rope were cut by means of a self-acting screw-cutting lathe designed expressly for the work. It was driven off the crank-shaft of the engines by means of an intermediate shaft and gearing. This drum had to wind from the respective depths of 390 and 450 yards; but it was contemplated winding eventually from the greater depth with both ropes. The drum worked well for some time, but in consequence of one rope having slipped out of the groove, this principle of drum was abandoned, and the ordinary flat drum substituted. The slip was owing in a great measure to the peculiar arrangement of head-gear, whereby the rope that slipped had to pass over two pulleys before descending the pit, thus causing an amount of slack rope between the pulleys, which no doubt was the only cause of the slipping.

In the diagram, Fig. 13, Plate 36, is shown an external conical winding drum made of wrought and cast iron, and having angle-iron for the grooves, the diameters being $17\frac{1}{2}$ ft. and $31\frac{1}{2}$ ft. It is driven by two cylinders, 36 in. diameter with 6 ft. stroke, and winds with 14 revolutions from a depth of 390 yards in 50 seconds, giving an average speed of 16 miles per hour; the quantity of coal raised is 85 tons per hour, being at the rate of 331 tons per hour per 100 yards depth. This drum has been in work since 1864, and no accident has to the writer's knowledge occurred.

In Fig. 14 is shown an external conical winding drum with wood lagging, of 16 and 27 ft. diameter.

In Fig. 15 is shown an external conical winding drum, with wood lagging having angle-iron bolted on it to form the grooves, the diameters being $20\frac{1}{2}$ ft. and 30 ft. This drum winds from a depth of 406 yards, and raises 120 tons of coal per hour, being at the rate of 487 tons per hour per 100 yards depth. The great advantage in its use is the saving of ropes, one pair of iron wire ropes having been in use for nearly four years, and having wound 1,000,000 tons of coal. The drum is driven by a pair of engines with 36 in. cylinders and 6 ft. stroke, and makes 14 revolutions; the time of

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winding is 45 seconds, giving 18 miles per hour as the average speed in the shaft.

In Fig. 16 is shown an internal conical winding drum made of iron, and having wood lagging with the grooves cut in it by means of a special lathe; the diameters are 18 ft. and 25 ft. This has been at work about eight years, and has given entire satisfaction. It is driven by two cylinders of 30 in. diameter and 5 ft. stroke, and winds with 22½ revolutions from a depth of 510 yards in 52 seconds, giving an average speed of 20 miles per hour; the quantity of coal raised is 56 tons per hour, being at the rate of 286 tons per hour per 100 yards depth. The ropes are of steel, 1¼ in. diameter, and last about three years.

The external conical winding drum at the Pemberton Colliery, shown in section in Fig. 10, Plate 36, and in the plan, Fig. 9, is believed by the writer to be the largest that has yet been erected. It weighs about 40 tons and is composed entirely of wrought and cast iron; the groove iron was specially rolled for it, and is so shaped that it is quite impossible for the rope to get out of the grooves.

Other modes of Counterbalancing.—In the North of England several kinds of counterbalance are used for winding engines; and for the particulars of these the writer is indebted to a paper read some years ago at another Institution by Mr. John Daglish.

The Pendulum counterbalance, shown in Fig. 18, Plate 37, consists of a weighted pendulum, which is raised by a chain attached to a drum on the shaft of the winding engine. At the commencement of the winding the pendulum is in a horizontal position, and the full weight of the counterbalance is acting to aid the engine against the load; as the winding proceeds up to the half-way point, an increasing portion of the weight is supported by the pendulum rod, which is then in a perpendicular position; and from this point until the load is brought to the surface the pendulum is gradually raised again to its horizontal position by the winding up of the chain, the counterbalance weight acting against the engine with gradually increasing force. In consequence however of the short travel of the pendulum, even with the smallest practicable chain-

drum, this system can only be applied to shallow pits; and as it is not these for which counterbalancing is of so much importance, the application of this plan may be considered as almost obsolete.

Another form of counterbalance, shown in Fig. 17, consists of a Lever or Crank of great strength, 20 ft. long, from the end of which a weight of 30 tons is suspended; and by means of intermediate gearing connected with the main shaft E of the winding engine the lever is made to describe a single semicircle during the whole of the winding, the action being thus the same as that of the pendulum. This counterbalance works a pit 336 yards deep.

In Fig. 19 is shown another form of counterbalance, called the Inclined-Plane counterbalance, in which a weight of 2 tons runs down a curved incline, and is then drawn up it again.

The system of counterbalance in general use in the northern collieries is the Chain counterbalance, shown in Fig. 20, and consisting of a long bunch of chain A, which at the commencement of winding hangs suspended in the top of a staple or shallow pit. The winding drum making 24 revolutions at each winding, B shows the position at the end of the third revolution, when the bunch of chain touches the bottom of the staple. C shows the position at the end of the sixth revolution, when the whole of the bunch lies at the bottom of the staple. At the meeting point, where the ascending and descending cages pass each other in the shaft, the whole of the large suspending chain, as well as the bunch, lies at the bottom of the staple, as shown at D. During the latter half of the winding the converse action taken place, the chain being drawn up out of the staple, and thereby producing a gradually increasing retardation upon the engine.

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TABLES.

Particulars of Colliery Winding Engines.

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Particulars of Colliery Winding Engines.

Reference No.	District.	Style of Engine. * *Counterbalanced.*		Cylinders. Number.	Cylinders. Diameter.	Cylinders. Stroke.	Cylinders. Effective Area of both cyls.	Piston Speed. Ft. per min. Mean.	Piston Speed. Ft. per min. Maximum.
				No.	In.	Ft.	Sq. In.	Ft.	Ft.
1	Cheshire	Vertical	Condensing	1	36	6	...	261	360
2		Do.	do.	1	60	7	...	340	350
3		Horizontal	Non-cond.	2	26	5	...	266	400
4	Derby-shire	Vertical	Non-cond.	1	36	6	...	456	600
5		Horizontal	do.	2	30	5	...	330	600
6		Do.	do.	2	26	4½	...	548	650
7		Do.	do.	2	20	4	...	280	560
8	Durham	* Vertical	Condensing	1	65	7	3300	176	250
9		* Do.	do.	1	68	7	3613	224	300
10		Do.	do.	1	68¼	7	...	...	...
11		Horizontal	Non-cond.	2	40	6	2460	253	410
12		Do.	do.	2	34	6	1780	291	522
13		* Do.	do.	1	48	6	1776	232	320
14		Do.	do.	2	36	6	...	...	...
15		Do.	do.	2	26	5	...	...	...
16		Do.	do.	2	34	6	...	...	...
17	F. of Dean	Beam		1	24½	8	...	180	360
18	Glo'ster-shire	Horizontal	Non-cond.	2	30	5	...	111	200
19		Do.	do.	2	24	5	...	113	220
20	Lanca-shire	Horizontal	Non-cond.	2	30	5	1400	260	462
21		Do.	do.	2	36	6	2000	288	432
22		Do.	do.	2	36	6	2000	376	720
23		Do.	do.	2	36	6	2000	...	...
24		Do.	do.	2	24	5	...	...	...
25		Do.	do.	2	30	6	...	...	...
26	Notting-hamshire	Vertical	Non-cond.	2	32	6	...	465	600
27		Do.	do.	2	32	6	...	420	540
28		Do.	do.	1	40	5	1230	300	...
29		Horizontal	do.	2	36	6	2000	376	...
30	Scotland	Beam	Non-cond.	1	20	4½	...	...	...
31		Do.	do.	1	16½	2⅓	...	...	...
32		Horizontal	do.	2	20	1⅞	...	...	...
33	South Wales	Vertical	Condensing	1	42	8	...	318	592
34		Horizontal	Non-cond.	1	24	6	...	390	870
35	Stafford-shire	Horizontal	Non-cond.	2	26	6	...	280	420
36		Do.	do.	2	20	3½	...	294	380
37	Yorkshire	Horizontal	Non-cond.	2	42	6	2720	360	700
38		Do.	do.	2	36	6	2000	228	...

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Particulars of Colliery Winding Engines.

Reference No.	Valves. Double-beat, Equilibrium, Slide, or Throttle.	Boiler Pressure. Lb. per sq. in.	Steam Pressure in Cylinders. Lb. per sq. in.	Vacuum in Cylinders. Lb. per sq. in.	Power. Gross Engine Power in each winding.	Duty. Weight of Coals raised through Height of shaft.	Duty. Per-centage of Power.	Load at starting in percentage of Pressure on Piston.	Maximum Indicated Horse Power of Engine.
		Lb.	Lb.	Lb.	Ft.-lbs.	Ft.-lbs.	₩ cent.	₩ cent.	I. H. P.
1	E	11	...	...	...	...	...	...	...
2	E	25	10	11	...	...	...	...	376
3	S	31	...	...	...	...	...	...	...
4	D	45	20	...	...	...	...	...	...
5	E S	45	37	...	...	...	...	...	...
6	E S	70	25	...	...	...	...	...	...
7	D	50	30	...	...	...	...	...	...
8	D	19	16	9½	10,342,350	7,729,344	75	50	...
9	D	20	19-20	10½	15,403,000	9,744,000	63	42	422
10	D	15	...	...	...	...	...	...	...
11	D	...	35	...	7,470,000	4,077,000	55	36	470
12	S	40	30-40	...	4,375,596	2,700,000	62	43	497
13	S	...	36	...	5,281,107	3,956,178	75	37	344
14	D	50	...	...	...	...	...	...	...
15	S	25	...	...	...	...	...	...	...
16	S	30	...	...	...	...	...	...	...
17	Lift	...	...	...	...	...	...	...	...
18	D	60	40	...	...	...	...	...	...
19	D	50	45	...	...	...	...	...	...
20	D	49	45	...	6,851,700	4,131,000	60	37	461
21	D	...	53	...	...	...	...	...	...
22	D	60-65	53	...	19,196,400	8,114,400	42	80	900
23	D	45-50	...	...	12,957,570	6,911,520	53	...	...
24	S	45	45	...	...	...	...	...	...
25	D	40	35-40	...	...	...	...	...	...
26	D	40	30	...	...	...	...	...	...
27	S	...	30	...	...	...	...	...	...
28	D	...	40-42	...	3,363,568	2,460,000	73	...	...
29	D	...	48	...	10,542,411	6,265,023	59	58	...
30	T	50	...	...	...	...	...	...	...
31	T	40	...	...	...	...	...	...	...
32	Cock	40	...	...	...	...	...	...	...
33	D	35	25	11	...	...	...	...	...
34	S	45	25	...	...	...	...	...	...
35	D	45	37	...	...	...	...	...	...
36	S	60	42	...	...	...	...	...	...
37	D	...	42	...	12,120,000	6,300,000	52	48	950
38	D	...	48	...	7,955,782	5,999,948	76	29	...

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Particulars of Colliery Winding Engines.

Reference No.	District.	Winding Drums.				Ropes.			
		Flat or Conical.	Diameter.			Hemp, Iron, Steel, Flat, Round, or Taper.	Size.	Weight per yard. (*Gross weight.)	Duration. *Those marked + are still at work.*
			Minimum.	Maximum.	Mean.				
			Ft.	Ft.	Ft.		In.	Lb.	Months.
1	Cheshire	Flat	...	12	...	I R	...	...	28
2		Flat	...	24	...	I F T	4½ to 3¾	13	18
3		Flat	...	14	...	I R	...	...	25
4	Derby-shire	Flat	...	15	...	I R	...	8	9
5		Flat	...	15	...	S R	...	8	11½
6		Flat	...	11	...	S R	...	8	... +
7		Flat	...	11	...	I R	...	8	6
8	Durham	Flat	25	27	26	I F	6½ × ⅝	21	18 to 24
9		Flat	22	25	23½	I F	6 × ⅝	21½	12½
10		Flat	...	21	...	I F	...	20	14
11		Conical	16	26	21	S R	1⅝ diam.	13½	14 to 24
12		Conical	16¾	18½	17½	I R	1⅜ diam.	10½	14
13		Flat	20¾	22¼	21½	I F	...	14	16
14		Flat	...	18½	...	I R	...	...	...
15		Flat	...	12	...	I R	...	*7¾ cwt.	...
16		Conical	16	24	20	S R	1⅝ diam.	24	... +
17	F. of Dean	Flat	9	11	10	I F	...	12	36
18	Glo'ster-shire	Flat	...	16½	...	S R	...	*40 cwt.	12
19		Flat	...	15	...	S R	...	*40 cwt.	18
20	Lanca-shire	Conical	18	25½	21¾	S R	1½ diam.	5½	36
21		Conical	19	30½	24¾	S R T	1½ to 1¼	9	47 +
22		Flat	24	28	26	S F T	...	11	18
23		Flat	20	23½	21¾	S F T	...	...	18
24		Conical	13	20	16½	S R	1 diam.	3¾	24
25		Conical	16	27	21½	S R	1⅜ diam.	7½	36
26	Notting-hamshire	Flat	15	17	16	F	...	8½	10
27		...	16	19	17½	R	...	9	24
28		Flat	13¼	15¼	14¼	I F	...	16½	...
29		Flat	15¼	18¼	16¾	I F	...	14½	...
30	Scotland	Flat	5½	8	6¾	H F	...	*9 cwt.	12
31		Flat	...	...	...	H F	...	*4 cwt.	15
32		...	...	...	...	I R	...	*3 cwt.	48
33	South Wales	Flat	21	22	21½	I F	6 × ⅞	*70 cwt.	15
34		Flat	11	13½	12¼	I F	4½ × ⅞	*27½ cwt	24
35	Stafford-shire	Flat	...	14	...	I R	1¼ diam.	...	20 +
36		Flat	...	9½	...	I R	1¼ diam.	...	14 +
37	York-shire	Flat	...	18	...	I & S, R	...	14½ & 11½	...
38		Conical	20½	30	27¾	I R	...	9	47 +

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Particulars of Colliery Winding Engines.

Reference No.	Pit Shaft.		Weight of Cage with Chains.	Total Weight of Tubs empty.	Weight of Coal raised.			Time of Winding.	Time of Banking.	Speed of Cage in Shaft.			Conductors.
	Diameter.	Depth.			At each lift.	Tonnage per hour.	Tonnage per hour per 100 yards depth.			Mean	Maximum.		Iron, Steel, or Wire-rope.
										Feet per min.	Feet per min.	Miles per hour.	Size in inches.
	Ft.	Yds	Cwt	Cwt	Cwt	Tons.	Tons.	Sec.	Sec.	Ft.	Ft.	Miles	In.
1	13½×9½	240	18	5¾	12½	35½	84	50	10	506	1131	12·8	Wood
2	12	686	21¼	4¼	32	44¾	307	65	50	1630	2037	23·1	Wood
3	10	270	18½	5¾	12½	50	135	33	7	1170	1760	20·0	Wood
4	9×8½	200	30	...	18	18¾	37½	20	10	1800	...	...	Wood
5	12½	305	40	...	32	26¾	82	35	50	1740	...	...	W
6	14	175	40	...	27	16¾	29	15	15	2100	...	...	W
7	13	135	35	...	18	30	40	20	10	1200	...	...	Wood
8	14	426	50	30	54	91	388	75	30	1020	1431	16·2	Wood 5×3
9	11½	580	35	33	50	72½	420	89	35	1180	1630	18·5	...
10	15½	591	...	24	45	31½	186	90	...	...	...	...	...
11	12	516	40	15½	24½	80	413	55	37	1689	2788	31·7	Wood 5×3
12	14	246	18	22	35¾	110	271	34	25	1302	2436	27·7	W
13	10½	322	22¼	16	36	65	209	45	50	1300	1706	19·4	Wood
14	14¾	240	...	20	33	...	...	...	...	...	...	...	...
15	12	108	...	10	16½	...	...	25	15	...	...	...	...
16	16	348	40¼	20	32	...	...	52	...	...	...	...	...
17	13×11	180	10	4½	13	34½	62	48	20	720	1421	16·1	I
18	10	444	30	12	42	63	280	60	40	1003	1890	21·3	Wood 4×4
19	9	488	20	7	24	30	146	75	35	1194	2319	26·4	Wood 5×5
20	16	510	20	12	24	56	286	52	25	1765	3100	35·2	I W
21	16	638	29	18¾	46	92	587	55	35	2088	3450	39·2	I, T rails
22	16	806	30	13	30	67½	544	55	27	2590	5100	57·9	I & S W $1\frac{7}{16}$
23	16	600	30	13	34	85	510	48	25	2166	4302	48·9	I & S W $1\frac{7}{16}$
24	12	414	25	10	26	62	257	60	15	...	...	...	Wood
25	14	280	22	10	28	71	199	55	15	...	...	...	Wood
26	12	515	32	12	30	50	257	45	50	2040	2280	25·9	Wood
27	...	...	36½	18	50	60	...	50	60	1860	2340	26·6	W
28	...	222	25½	15	33	91	202	30	30	1320	...	...	...
29	...	413	30	25	45	128	529	45	25	1652	...	...	...
30	10×6½	100	8½	3	8	10	10	18	...	...	...	...	...
31	9×5½	30	6	2½	6½	7¾	2½	16	...	...	...	...	...
32	10	80	6	2½	7	8¾	7	18	...	...	...	...	...
33	22×18	300	40	20	60	135	405	40	20	1350	1590	18·1	W 1⅛
34	18×9	120	22	8½	22	45	54	40	42	617	870	9·9	...
35	12½	240	28	14	20	62½	150	24	90	1100	1525	17·3	S W 1⅜
36	7	225	12	4½	12	24	54	20	90	1200	1675	19·0	Wood
37	...	450	48	19	40	102	459	47	21	1691	3080	35·0	...
38	...	406	48	22	44	120	487	45	25	1624	...	...	...

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Mr. JEREMIAH HEAD, referring to the abandonment of the back piston-rod in horizontal steam cylinders, mentioned that he had some large engines at work with back piston-rods, and thought the plan was worse than useless. If the back slide was packed up sufficiently to carry any part of the weight of the piston, the rod was inevitably sprung upwards out of line; and the effect of the tail piston-rod was to work an oval in the back stuffing-box. If, as was generally the case on that account, the back slide was omitted, the overhanging piston-rod produced a similar result by the leverage of its weight. As a means of obviating the tendency of the cylinder to wear oval, one plan that had occurred to him was to measure the exact deflection of the piston-rod with the piston upon it, before introducing it into the cylinder, and then, after carefully warming it, to give it by means of screws a set of an equal amount in an upward direction, so that it should become truly horizontal in working; if that could be done, he thought it would make a perfect job. Another plan he had thought of was to set the bottom of the cylinder, and the slides of the front and back piston-rods, approximately parallel to the catenary which the piston-rod and piston would assume when transversely supported on the slide-blocks. It was obvious that the piston-rod would thus be always working with its particles so strained as to carry the piston and relieve the bottom of the cylinder. In this way the oval wear of the cylinder and of the glands might be reduced to a minimum.

Mr. E. REYNOLDS agreed in considering that it was altogether undesirable to have the piston-rod prolonged through the back end of the cylinder in a horizontal engine, though this was found necessary in many modern foreign locomotives, probably owing to the use of wrought-iron or steel pistons, which being proportioned with reference only to the theoretical requirements of strength had very narrow bearing surfaces and therefore cut the cylinders. The simple remedy for wear of the piston was to have plenty of bearing surface, which would remove all necessity for back rods, except where steam-jackets or superheated steam

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were used: in these cases back rods or very strong single piston-rods had sometimes been found necessary to resist the jarring action arising from the dryness of the sides of the cylinder.

One thing worth calling attention to was the modern fashion of making winding engines excessively large in proportion to their work: the cylinders were made large enough to command three or four times the load actually raised, the object being to enable them to start very quickly. This quick starting involved a strain on the rope much greater than the simple amount of load attached, and thereby shortened the life of the rope. It had been mentioned that with certain of the drums described in the paper the ropes had lasted four or five years; but those drums were described as being 30 ft. diameter and 40 tons weight, and the inertia of this large mass would absorb a large proportion of the surplus power of the engines at the commencement of the winding, and so relieve the ropes from undue strain. The large diameter of the drum and pulleys would also very much prolong the life of the ropes, particularly of the one which wound on under the drum, reversing the direction of the bend over the pulley at the pit head. Where the usual size of these pulleys was from 8 to 10 ft. diameter, the lower rope did not last on the average more than half as long as the upper one; whereas this difference rapidly decreased as the size of the pulleys was increased, so that it was not very conspicuous where such large sizes as those described in the paper were used. In a particular case where the pit-head pulleys were 15 ft. diameter and the drum 16 ft. diameter, the wire ropes being $1\frac{1}{4}$ in. diameter, no difference had been traced in the wear of the two ropes.

Mr. Benjamin Walker considered the great weight of the drum in modern winding engines, which caused it to act as a large flywheel, was a decided advantage, and in conjunction with the long stroke adopted must prove an important source of economy in the working of the engines. He suggested that if a few indicator diagrams could be obtained from some of the winding engines described in the paper they would be of much interest for comparison with those obtained

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from other engines, and he had no doubt would show favourably in connection with the consumption of coal for the work done. The vertical engine was the one he preferred for winding purposes, rather than the horizontal; it was an excellent type of engine, and gave capital results in economy of working. The guide for the back piston-rod in horizontal cylinders he had for many years abandoned, considering it to be only a make-shift and of no practical benefit. He had made the piston-rod flat at the bottom, working through a gland with a corresponding flat side, which had been found to work very successfully; there was no difficulty in fitting the rod and gland so correctly that they would work just as well as in the case of an ordinary round piston-rod, while the flat bearing surface had the advantage of being more durable.

Mr. W. Rye was satisfied it was an advantage as regarded the durability of the cylinder to do away with the back piston-rod altogether. He had had very little occasion to rebore horizontal cylinders on account of their wearing oval, and had known horizontal engines work for twenty years without the cylinders being rebored; where however engines had a large amount of work to do, it was likely the cylinders might want boring again in only ten years' time. He should be glad to hear what had been the experience of others as to how far and under what circumstances the cylinders really did wear oval in horizontal engines; or if it was not better to ignore the back piston-rod altogether as a useless appendage.

Mr. H. Davey enquired to what extent expansive working was now carried in winding engines. This was one of the most important subjects connected with winding engines, and one that had occupied the attention of engineers for many years; but he was not aware that any great success had yet been attained in that direction. Various constructions of expansion gear had been proposed for winding engines, and he should be glad to know how far any of them had been successful in practice.

He quite agreed in the desirability of providing winding engines with a condenser worked by an independent engine, which was a

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most important point. Winding engines had previously been made with condensers attached, but a condenser so applied could not keep the vacuum perfect during the time the engine was stopped.

With reference to the question of horizontal cylinders wearing oval, he thought there was no difficulty from that cause with good metal, and with the supporting surface of the pistons large enough in proportion to their weight. Pistons were often made with a very narrow supporting surface and of great weight, and in such cases there must inevitably be great wear. Instead of this, the piston should be made as light as was compatible with its required strength, and of sufficient length to give very wide bearing surfaces in the rims of the piston; for the spring packing-rings had no supporting power, the whole weight being carried by the rims of the piston itself. The back piston-rod he agreed in considering might well be dispensed with as worse than useless.

In the section shown in Fig. 6 (Plate 32) of the double-beat steam and exhaust valves used in one of the horizontal winding engines, he noticed that the double seating of the steam valve was not made all in one piece, but consisted of two distinct seats fixed in separate parts of the nozzle. Having put similar valves in an engine some years ago, he had not succeeded in getting them to keep steam-tight, and had had to replace them by the ordinary form of Cornish double-beat valve. The difficulty arose from the unequal expansion of the two metals, the seats being fixed in the cast-iron nozzle, while the valve was made of gunmetal; when heated the two seats separated less than the increase in length of the valve, so that the valve became longer than the seating, and there was consequently a leakage at the upper seat. He enquired whether this difficulty had been experienced with the valves shown in the drawing.

Mr. H. Lawrence mentioned that he had seen double-beat valves like those shown in the drawing (Fig. 6, Plate 32) in extensive use on American river steamboats, and had not heard of their giving any trouble. He had himself overcome the difficulty of unequal expansion in valves of that description by using a

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special mixture of metal for the cast-iron nozzle carrying the two seats; and also by introducing a sliding joint in the valve-spindle between the upper and lower beats, and leaving a little vertical play between them, so that both of them were able to close steam-tight under all circumstances.

One thing which had struck him most of all in connection with the present paper was the great difference in the durability of the ropes, many not having lasted more than eighteen months, while those working upon the conical drum shown in Figs. 8 and 9 had already continued in use nearly four years to the present time. At the collieries in the North of England it had gradually become the practice to make the head-gear pulleys as nearly as possible the same diameter as the flat winding drums, so that the ropes might not receive any greater amount of bending in passing over these pulleys. It appeared to him however that the long duration of the ropes on the conical winding drum could not be attributed to that circumstance, because the diameter of the conical drum itself varied from 20 to 30 ft. in the portion on which the ropes wound, and the bend of the ropes was thus continually altering; notwithstanding which there was the fact that the ropes on the conical drum had already lasted since 1871, while those on the flat drums lasted only about eighteen months. This difference in duration must be a serious matter to colliery proprietors, and it was important to ascertain to what cause it was to be attributed. In ropes winding on flat drums, the successive coils of the rope had a grating and wearing action against each other; whereas in the conical drum each turn of the rope had its own separate groove, and instead of wearing at the sides it was not in contact with anything but the correctly shaped surface of the groove. This he thought might account for the saving in the wear, even to the extent of the great difference between eighteen months and four years.

In reference to the small use of condensing engines for colliery winding, he mentioned that in the county of Durham there were many condensing engines in use for that purpose, which were working in a most efficient manner.

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Mr. W. S. Hall observed, in regard to the size of the pit-head pulleys and the wear of the ropes, that if the pulley was made too large in diameter it acted as a flywheel, and would then overrun the rope in stopping or starting quickly, and wear a flat place in the rope at that part. He had frequently noticed this occur in a very marked manner when stopping quickly, and that would account for the wear of the rope.

Mr. C. Cochrane, referring to the question asked respecting the wear of horizontal cylinders, mentioned that in the case of some of Mr. Slate's horizontal blowing engines, having blowing cylinders 4 ft. diameter and 2 ft. stroke and running at 60 or 70 rev. per min., a serious wear took place, owing to the weight of the wrought-iron piston having no back support; and after the lapse of a few years it became necessary to take the cylinders out and rebore them, the wear being chiefly at the back end. To prevent a recurrence of this wear, the piston-rod of 5½ in. diameter was prolonged, and carried through the back cover of the cylinder, and worked through a stuffing-box 18 in. long attached to the cylinder cover, so as to afford a larger total extent of bearing surface, which proved a great advantage. The brasses carrying the piston-rods were in halves, the lower halves having vertical adjustments so as to take up the wear; and the exact adjustment of the piston-rods to the particular level desired was tested at regular intervals by careful gauging. This alteration had been attended with considerable success in preventing unequal wear of the cylinder. The result showed the importance of relieving the cylinder as far as possible from the duty of bearing any of the weight of the piston; and in all cases the weight of the piston was made as small as possible.

Mr. D. Adamson thought the wear of a horizontal blowing cylinder could not well be compared with that of the steam cylinder of a horizontal winding engine, because the interior of a blowing cylinder was exposed to the gritty atmosphere usual in an ironworks, while the inside of a steam cylinder was clean and free from grit, receiving only steam; and this consideration

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seemed sufficient to explain why in some engines it was found there was no necessity at all for reboring the cylinders, while in others reboring was required. He agreed in preferring that the back piston-rod should not be used; it not only occasioned friction and loss of power, but it could not be got to work well for any length of time, as a series of bearing surfaces in the same straight line were always difficult to maintain. Cylinders that had come under his own notice had had a much shorter life in work where the piston-rod had gone through the back end. It had been recommended that care should be taken to have a good class of metal; but that was a very indefinite mode of expression, as there were various notions of what constituted a good class of metal. In his own experience he had found that, to obtain a metal possessing the utmost slipperiness of surface, manganiferous iron must be used. For heavy castings where great tensile strength was required, spiegeleisen should not be employed; but if an iron was wanted that would be good for turning and boring, as in the case of steam-engine cylinders, a manganiferous iron must be used in such proportions as would render it most suitable for undergoing those operations. Spiegeleisen alone did not give a metal such as was required, because it contained from 8 to 10 per cent. of manganese, which was too large a proportion; but 2 or 3 per cent. of manganese was the best for giving a good slippery surface, which would continue in the best possible order in working, and was consequently adapted for horizontal stationary and locomotive cylinders, and for other sliding surfaces. He had for some years adopted a mixture of North Lincolnshire manganiferous iron with hæmatite and a little Scotch pig, in order to get fluidity in melting; such a mixture gave a close metal, which while difficult to file could be turned and bored with great facility. Where certain definite results were desired, it was important that care should be taken to have iron of the exact character necessary; and this could be obtained with the simple ingredient manganese, used in the proper proportion for the quality of iron required, as for steam cylinders, slide valves, or motion bars.

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Mr. W. Howe mentioned that one of the first horizontal winding engines had been put down at the Clay Cross Colliery about 36 years ago by Mr. George Stephenson, and after it had been working for ten years there was a good deal of leakage past the piston, which was accordingly taken out for reboring the cylinder. He had then found that the cylinder was worn barrel-shaped, the wear being quite as much at the top as at the bottom, and it was not worn oval transversely. That engine was still working satisfactorily, without having had anything further done to it in the way of reboring; it had a back piston-rod, as had also all the other horizontal engines at Clay Cross, but that was the only one which had had the cylinder rebored.

Another winding engine at the Clay Cross Colliery was a vertical engine somewhat similar to that shown in Figs. 1 and 2 (Plates 28 and 29); and after working for some years with the ordinary cast-iron packing rings, it had suddenly stopped working, though it had been examined not long before. On taking the cover off, it was found that the packing rings were broken into a great number of pieces. As it was a matter of the greatest importance that this should be remedied as speedily as possible, and there was not time to fit in new cast-iron packing rings, an ordinary ring was cast, thick enough to fill up the space occupied by the previous packing, and was fitted with a couple of Ramsbottom rings made of brass. This plan had worked excellently; the rings were changed every two or three years, but the cost of renewal was so exceedingly small and the efficiency so great that the plan was still adhered to.

With regard to the double-beat steam valves shown in the drawing (Fig. 6, Plate 32), he had had an engine working at Clay Cross for 21 years with similar valves, and had had no leakage from unequal expansion. In that case the top seating of the valve was made so slightly conical as to be almost cylindrical, the bottom seating alone being the usual cone, so that expansion did not affect the fit at all; and he had never noticed any leakage going on through these valves.

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Mr. T. Claridge said he had overcome the difficulty of unequal expansion in double-beat valves of the construction shown in the drawing by making the valve itself of cast iron as well as the nozzle. It was simply necessary to make the valves of good tough iron, with a little greater thickness of metal than in gunmetal valves, and when so made they were stronger than gunmetal valves and would wear very much longer; he had known them work for 25 years. The cast-iron valves were cheaper not only in first cost but also in total expense.

Mr. W. J. L. Watkin mentioned that in the particulars he had furnished for the paper as to the winding engines at the Pemberton Colliery, which had been visited by the members at the Liverpool meeting of the Institution three years ago, the duty of the engines had been understated, and the quantity of coal that would eventually be raised by the same engines in regular working would be considerably greater than the amount given in the paper. At present there was not a satisfactory arrangement for changing the tubs quickly; with conical drums there was always a difficulty in this respect, unless some special means were adopted. The drum in this instance had a minimum diameter of 19 ft. and a maximum of 30 ft. 6 in.; consequently when the cage arrived at the top landing the tubs were being changed with a drum of larger diameter by 11 ft. 6 in. than was the case with the tubs which were being removed at the bottom of the shaft at the same time. At present one deck was thus lost in changing, and the engine had to be moved once more than would be necessary when suitable apparatus was erected for acting upon the cage at the bottom of the shaft in such a manner as to dispense with any additional movement of the engine. The time occupied in changing six tubs in each cage was now 35 seconds; but when the alteration was made a saving of 7 seconds would be effected, which would enable the engines to raise 150 tons of coal per day more than at present.

With regard to the wear and tear of the ropes at that colliery, he attributed their long duration to the careful manner in which the grooves on the winding drum had been prepared by the author of

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the paper. There was not the slightest grating of the ropes in the grooves during the whole course of the winding, and there was scarcely any noise whatever. The ropes, which were made by Messrs. Haggie of Gateshead, had now been at work since September 1871, and he could not yet find the slightest defect in them.

The PRESIDENT enquired whether any difference was found in the durability of the two ropes, in consequence of the reverse bending given to the one which passed underneath the winding drum.

Mr. W. J. L. WATKIN replied that the rope which passed under the winding drum used generally to wear out sooner on that account than the one which passed over it; and with the drum at Pemberton Colliery he thought three months' shorter duration a fair allowance to make for the under rope.

Mr. W. BRYHAM considered the conical winding drum at Pemberton Colliery was the best that had yet been made; the ropes used with it were exceedingly strong round ropes. At Rose Bridge Colliery, with a flat winding drum and flat taper ropes, the wear and tear of the ropes was apparently greater; but in proportion to the weight drawn the flat ropes at that colliery were lighter, being as light as could possibly be used, and no stronger than sufficient to do the work for a certain length of time with safety, as there was not engine power enough to allow of using heavier ropes.

The PRESIDENT enquired whether there was any saving of wear in consequence of letting each convolution of the rope bed in its own separate groove, instead of heaping itself on the preceding turn.

Mr. W. BRYHAM replied that he had had one of the internal double-cone winding drums at work at another pit for eight years, and had not taken the ropes off till they had been working four

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years. They were then changed, lest the wire might be getting bad inside; not that it was seriously worn, but lest it might have lost its tensile strength from constant concussion. The long wear of the ropes in that case proved the advantage of the drum being made with grooves properly fitting the ropes; moreover the drum being covered with a wood lagging, the grooves were of wood, not of iron, which was also a great advantage.

The PRESIDENT enquired in what distance the cage could be brought to rest when moving at the maximum speed of 60 miles per hour in the shaft.

Mr. W. BRYHAM replied that the engineman shut off the steam and began to reverse the engine about seven revolutions before stopping, the ascending cage being then about 180 to 200 yards from the top; and the steam had to be admitted against the engine in the last two or three revolutions. Up to the time of shutting off steam the engine was running at its full speed, and he understood from the author of the paper that the speed in the shaft was then 60 miles an hour.

Mr. G. H. DAGLISH said he was indebted to Mr. G. Fowler for kindly measuring the speed in that and other instances, by means of a special instrument for the purpose; and he believed the maximum speed was not overstated at 60 miles an hour in the shaft.

Mr. W. BRYHAM said he had been a little surprised at hearing the rate stated so high; the speed depended however upon the man driving the engine, and it was possible for the engine to be driven so fast as to give a speed of 60 miles an hour in the shaft.*

With regard to the abandonment of the back piston-rod in horizontal winding engines, the engine referred to by the author of the paper (shown in Fig. 5, Plate 32) was one that he had had to

* The actual velocity of the cage in the pit at the point of greatest speed has been subsequently ascertained to be 57 to 58 miles per hour in regular working.

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do with for a long time, and it had been originally made with the piston-rod carried through the back end of the cylinder, not with the intention of supporting the weight of the piston, but for working a small feed pump, which however had not been used as a pump except for a very short period. Finding that the back piston-rod was no advantage and was only occasioning a waste of packing, he had had it cut off a few years ago both in that engine and in the rest of the horizontal engines under his charge, all of which had previously had back rods; since then he had found less waste in packing. The cylinder of that engine, which had been at work for 22 years, was 36 in. diameter and 5 ft. stroke, and he had not found there was any wear upon it whatever; it was just as true in its circumference now as it had been at first.

Mr. J. R. Waddle remarked that a good deal more importance seemed to be attached to the back piston-rod than he thought it merited, for in his own experience he had found it neither did much good nor much harm. Where a slide-block had been applied at the end of the back piston-rod for carrying the weight of the piston, it had been efficient enough for that purpose; but it was remarkable that the only horizontal cylinders which he had rebored had been worn at the top, while the bottom of the cylinder had been quite uninjured.

Mr. G. H. Daglish, in reply to the enquiry about expansion valves, said he was not aware of any having been tried for winding engines, none having come under his notice.

With regard to the back piston-rod, a horizontal winding engine which had been put up in 1860, and had been constantly at work ever since, had worked with a back slide till 1870, when the rod was removed; and the cylinder on being gauged recently was found perfectly true in shape, not worn at all oval during the five years' work since the removal of the rod.

The double-beat steam valves shown in the drawing had been found to give very little trouble, which he thought was due to the fact that both the valves and the seats were cast of the same metal, all of them being of gunmetal.

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The particulars given respecting the time of winding with the different engines referred to in the paper had been kindly supplied to him from different districts, and he hoped the comparison thereby afforded would be useful.

The PRESIDENT considered the subject of the paper was a most important one, because upon the efficiency of the winding machinery depended the safety of the men who were lowered into the mine and raised from it by that means, as well as the power of turning out a sufficient amount of coal per day to yield a profit on the working.

The suggestion had been made in the paper that it would be well to have condensing engines introduced for winding, and to employ with them a separate engine for working the air-pumps. At the time when the Blackwall Railway was worked by ropes, the stationary engines used for the purpose, which were of the marine type, had their air-pumps separate and worked by an independent pair of beam engines of 12 H. P., and thus the large engines were always ready to start when the signal was given. The suggestion might be practicable for colliery winding engines; but he thought one of Morton's ejector condensers would be particularly applicable to these engines. Although it did not give the very best vacuum, yet a sufficiently good vacuum would be obtained by that means; and it went to work immediately upon the engine starting, the first stroke putting the whole into operation.

In reference to the utility of the back piston-rod, the discussion upon this point had borne out the opinion that it did harm rather than good, and did harm even when an additional slide was provided to carry the back end of the rod. The best plan seemed to be to make the piston as light as possible, with a large amount of bearing surface, and the cylinder of a good quality of metal, and to do away with the back piston-rod altogether. He was glad Mr. Adamson had explained how this good quality of metal could be obtained, the phrase being a very ambiguous one; and they were much indebted to him for the practical information he had given.

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No allusion had been made in the paper to the means taken for ensuring safety in stopping, for the prevention of overwinding. He should have been glad to hear remarks on this subject, because accidents had arisen from overwinding, notwithstanding that the usual breaks were employed; and it would have been well that what was known upon this point should be discussed. This might perhaps be done on a subsequent occasion.

He moved a vote of thanks to Mr. Daglish for his paper, which was passed.

The Meeting was then adjourned to the following day.

In the afternoon the Members visited the Pomona Exhibition of Machinery in Manchester, on the invitation of the proprietor, Mr. James Reilly, by whom they were entertained at luncheon at the Exhibition. The Atmospheric Gas Engine that had been described at the meeting was seen in operation at the Exhibition, working a hoist. Messrs. Haworth's Spinning Mill, Messrs. Chadwick's Paper Works, and Messrs. Horsfall's India-Rubber Works were also visited by the Members. In the evening the Members visited the Cheetham-Hill Exhibition of Machinery, on the invitation of the Society for the Promotion of Scientific Industry, by whom refreshments were kindly provided at the Exhibition.

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The Adjourned Meeting of the Members was held in the Town Hall, Manchester, on Wednesday, 28th July, 1875; FREDERICK J. BRAMWELL, Esq., F.R.S., President, in the Chair.

The following paper, communicated through Mr. John Robinson of Rochdale, was read:—

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ON WOOD-WORKING MACHINERY.

By Mr. THOMAS N. ROBINSON, of Rochdale.

The general employment of Machinery for the Conversion of Timber is of comparatively recent introduction. Owing in great measure to the ease with which timber can be worked with hand tools, it was not until the greater extension of all kinds of engineering enterprise, in which timber in various forms plays such an important part, that the greatly increased and ever increasing demand for converted timber compelled the adoption of a more rapid mode of production, which was only to be obtained by substituting mechanical for manual labour.

As yet the various principles involved in the working of wood-cutting machinery have had very little theoretical investigation, almost all the present knowledge of them being the result of practical observation and experience.

In considering this subject it will be found convenient to divide it into the following parts:—

I.—The Cutting Tools.
II.—Their Speed.
III.—General Construction of Wood-Working Machines.
IV.—Examples of Machines used in the Conversion of Timber.

I.—The Cutting Tools.

In the operation of cutting tools on timber there are two actions—one of splitting, and one of cutting or dividing the material by the action of a sharp edge against it. The action of splitting always takes place when soft timber is worked in the direction of the grain. The action of cutting takes place in the working of all kinds of timber across the grain, and in working in the direction

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of the grain in hard wood, the fibre of which is too close and irregular in its direction to allow of splitting. Therefore all tools for the working of timber, no matter of what form, have their cutting edges adapted for either one of these two actions.

For the working of timber there are three classes of tools:—

Saws—which are used for merely dividing the material.

Cutters—which are used for finishing the material to exact forms, leaving smooth surfaces.

Boring Tools.

Saws.—Almost all timber, if struck a sharp blow in the direction of the grain with the edge of a wedge-shaped tool, will split down in that direction. This is precisely the action of the teeth of saws. They are like a number of small wedges striking the material a series of sharp blows, and splitting the fibres of the timber apart as they advance, at the same time clearing their way by ripping out the loosened fibre immediately in their path, and producing a stringy sawdust.

In Fig. 1, Plate 38, is represented the form of tooth generally used for cutting soft wood in the direction of the grain. The cutting angles A B D and C B D are both acute angles, measuring respectively about 70° and 50°. The top C B and the face B D in each tooth are bevelled off to sharp edges alternately to one side and the other, so that in their action the point B first enters the material, and like the point of a wedge acting in two directions: through a very short distance across the timber, so as to prevent its splitting too far, and through a much greater distance in the direction of the grain, so as to give the former action greater regularity and power. The stringy sawdust produced by this form of tooth is apt to clog itself fast between the teeth unless plenty of room be left for it to collect there; on this account these teeth have always to be made pretty long and a good distance apart. It is found that the best number of teeth for a circular saw, no matter what diameter, is forty-two; for as the saw increases in diameter, it cuts more sawdust, and consequently requires greater space between the teeth for this to collect there.

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In operating on hard wood the action of the saw is somewhat different to its action on soft wood. With hard wood the grain does not run regularly with its length, but frequently across; the fibre is also closer and more compact, so that the tendency to split in the direction of its length is very slight; hence the teeth of the saw have to make their way by cutting alone. But as the resistance of the material is great, the teeth can remove only a very small portion of it at once, so that their action becomes one of scraping rather than cutting. In Fig. 2, Plate 38, is represented the form of tooth used for operating on hard wood. The cutting angles A B D and C B D are much less acute than those in Fig. 1, measuring respectively 85° and 65°; there is here less necessity for the wedge shape, the work being performed principally by the point B scraping as it were against the material; and as it is necessary to keep this point sharp as long as possible, the angle must be made large to give it greater strength. These teeth are also much shorter and closer together than those in Fig. 1, the sawdust produced by the scraping action being finer, so that it has not the same tendency to clog between the teeth.

In operating across the grain of timber there is no tendency whatever to split in the direction of the cut; the work to be done consists simply in severing a number of fibres, which are held together perfectly rigid. This can only be done by sheer cutting; hence the teeth of the saws are like a number of lancets, being sharpened to a keen edge on the face, which is set well back, as shown in Fig. 3, to prevent the point from hooking into and displacing the fibre.

In the working of saws, in order to lessen the friction which would be produced by the rubbing of the blade through the way cut by the teeth, what is termed "set" is given to them: that is, the teeth are bent outwards alternately on each side, so that the way cut is wider than the blade of the saw, thereby giving it clearance.

Cutters.—The action of cutters on timber is very similar to that of saws, with the exception that with saws the whole of the material directly opposed to the cutting edge is removed, whereas with a

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cutter it is only partially removed, and what remains has to be left with a perfectly smooth surface. Like saws, cutters in their action on soft wood with regular grain perform their work with a splitting action; but as the surface has to be left smooth, it is necessary to make the cutting angles as small as the edge will stand, so as not to disturb the fibres of the material beyond the required depth of cut.

In Fig. 4, Plate 38, is represented a cutter and cutter-block used for working soft timber. This form of cutter-block is the kind most generally used in practice, the angle A B D being of a medium size, so that it is adapted for different kinds of timber. The best size for the cutting angle C B D is found to be 25°; when it is made less, the edge becomes too weak to stand.

In the operation of cutters on hard wood, the material being of such a nature as to resist splitting has to be removed by actual cutting. In Fig. 5 is represented a cutter and cutter-block for cutting hard wood. In operating on hard wood, the best results would be obtained by the cutting angles A B D and C B D being as acute as possible; but in practice the difficulty is to prevent the edge breaking off or turning, owing to the great resistance offered by the hard nature of the material. It is therefore found necessary to make the cutting angle C B D much less acute, in order to give the edge sufficient strength, and enable it to operate like the hard-wood saw by scraping with its point. In Fig. 5 the cutter acts nearly at right angles to the material, and is sharpened to an angle of about 60°.

Cross-cutting cutters are always made so that they attack the material diagonally to the grain, as it is found that the nearer a cutter can be brought to act in the same direction as the grain, the smoother is the surface left by it. The fibre is generally severed by what is called a shoulder-cutter or an assistant cutter acting something like a cross-cut saw.

In Figs. 6 and 7, Plate 39, are represented side and face views of a cutter and cutter-block used for tenoning. S is the shoulder-cutter which severs the fibre, and C the cutter which removes the material to form the tenon. The latter is set diagonally to the

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direction of the fibre of the material; its edge is also slightly helical, which gives it a continuous action on the material, and prevents the jarring caused by cutters coming abruptly with their whole cutting edge at once into contact with the work. This enables the timber to be fed much steadier through the cutters, thus producing a smoother surface and preventing the edge of the timber from being broken off as the cutter passes out of its work.

Boring Tools.—A boring tool is a cross-cutting cutter, and acts on timber in a similar manner to a tenoning cutter working at the end of a radius from an axis perpendicular to the plane on which it acts. It is important in the working of boring tools that they should not become obstructed by the cuttings as the tool descends through the timber. On this account they are generally twisted in a spiral form from their cutting edge, so as to lift out the material as it is cut away.

II.—Speed of Cutting Tools.

The speed of cutting tools acting on timber is mainly limited by the ability of the machines to withstand vibration and excessive wear and tear. Hence the speed is found to vary according to the kind of motion by which it is produced and the possibility of the motion being perfectly balanced. For this reason all machines in which the cutting tools are worked with a reciprocating motion run at a very much slower speed than those with a rotary motion; for, unless the machinery is greatly complicated, the reciprocating motion can only be approximately balanced by a rotary one.

For vertical reciprocating saws cutting logs and deals, the speed varies from 100 to 300 rev. per min., according to the weight of the moving parts.

With circular saws the speed is limited by that at which the circumference of the saw will continue to run true. When the speed rises beyond a certain point, the blade of the saw springs with the extra strain brought to bear on it by the increased force with which the teeth strike the timber; so that the saw is found to cut easier when running at 9000 ft. per min. than it would at a higher or lower speed.

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III.—General Construction of Wood-working Machines.

It has just been stated that the speed of wood-working machines is mainly limited by their ability to withstand vibration; for vibration not only accelerates wear and tear in the moving parts, but it is communicated to the cutting tools, and so prevents the production of true work. It has been found by practical experience that the best way to get rid of this vibration is to resist it by making the frames of the machines in the most rigid form possible; hence the most distinctive feature pervading the construction of this class of machinery is the general use of cored sections in the frames, which wherever possible are made in one entire casting, and where that is not possible the number of separate parts is reduced to a minimum. This is the very opposite principle of construction to that of the earlier wood-cutting machines, in which the frames were made entirely of wood, being intended to absorb the vibration instead of resisting it.

IV.—Examples of Machines used in the Conversion of Timber.

As the limits of this paper will not permit a separate description of all the different machines now commonly used in the conversion of timber, the writer has selected two machines for detailed description:—the Horizontal Single-bladed Saw Frame, representing the class of machines used for operating on rough trees or logs; and the Planing and Moulding Machine, representing the class of machines used for finishing the timber with a smooth surface.

The *Horizontal Single-bladed Saw Frame*, which is shown in front elevation and plan in Figs. 9 and 10, Plates 40 and 41, though of recent introduction, is a machine now very extensively used for fine sawing from rough logs. It is very useful in the working of expensive kinds of timber, such as mahogany, where it is desirable to examine the timber after each board or panel is cut off. The timber A is made fast by means of screw cramps B B on the table C, which travels with small grooved wheels on rails, and is worked backwards and forwards from the shaft D by a rack and pinion. When the timber has to be fed for sawing, the

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shaft D is worked by throwing the clutch E into gear with the worm-wheel G, the worm-shaft H being driven by speed pulleys from the main driving shaft J of the machine. If the table is required to be run at a quick speed backwards after the timber is cut through, or forwards to bring the timber into position to commence sawing again, the shaft D is worked in either direction by throwing a clutch into gear with the bevil wheels K, which are driven in opposite directions by a bevil wheel worked through spur wheels by a pulley direct from the line shaft.

The saw frame F receives a reciprocating motion from the main driving shaft J of the machine through a disc-crank and connecting-rod, and works in slides in a cross frame L, which can be raised and lowered to vary the thickness of cut by means of a handle and screws M. The main driving shaft J can also be raised and lowered in the same way, so that the angle at which the connecting-rod works to the slides may be always kept the same for the forward and backward strokes. In Figs. 11 and 12, Plate 42, are shown an elevation and plan of the saw frame F and slides L L; and Fig. 13 is a transverse section to a larger scale. The saw S is held in the frame F by means of buckles fitting loosely in square holes at the ends of the cross rails of the frame, so that the saw can be tightened up by the nuts which are screwed on the ends of the buckles. The ends of the centre rail of the frame are let into the cross rails up to a shoulder; and the cross rails are fastened to the slide-blocks by means of pins, Fig. 13, on which they are free to turn, so as to prevent the tightening up of the saw from affecting the slide-blocks and causing them to bind in the slides.

The feed motion of this machine being a continuous one, it is necessary that the cutting should also be continuous; therefore the saw teeth are shaped to face opposite ways in the two halves of the length of the saw, as shown in the plan, Fig. 12, one half of the teeth to cut during the forward stroke, and the other half during the backward stroke. The slides L L carrying the saw frame, instead of being set in line with each other and parallel to a line drawn through the points of the saw teeth, are set out 'ne in plan, Fig. 12, so that their inner ends are $\frac{1}{4}$ in. further

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from the line of the saw than their outer ends. Supposing the saw to start on its forward stroke cutting with the teeth T, Fig. 16, these teeth gradually move forward to the timber, in consequence of the leading slide-block ascending its incline; whilst the non-cutting teeth N in the hinder half of the saw gradually fall back, in consequence of the following slide-block at the same time descending its incline, so that the teeth which are not cutting keep quite clear of the timber as it advances. The obliquity of the saw in the extreme positions of its stroke is illustrated on an exaggerated scale in the diagram, Fig. 16. The slide-blocks, which are shown separately in front elevation and transverse section in Figs. 14 and 15, are made so that their centre part, to which the saw frame is fastened, can swivel on their top and bottom edges which work in the slides, and can thus travel freely without binding.

This machine can be driven at a very much higher speed than any vertical reciprocating saw, on account of the lightness of the moving parts and of their being more accurately balanced, through the saw cutting during both strokes, and in consequence of there being no need to balance the weight of the saw frame, because that is horizontal. It has a stroke of 30 in., and works at a speed of 240 double strokes per min., so that the saw travels at a rate of 1200 ft. per min.; in contrast with this, the speed of the vertical frame does not exceed 600 ft. per min. Another great advantage this machine has over the vertical single-bladed saw is that the timber can here be fixed firmer on the table, whereas with the vertical frame it has always to overhang to the extent of the thickness of the cut.

The *Planing and Moulding Machine*, represented in elevation and plan in Figs. 17 and 18, Plates 43 and 44, is used for planing all kinds of boards on both the top and bottom sides and the edges at one operation, and also for cutting mouldings to any pattern. The timber A is fed through the machine by means of four calender rollers B B, and passing first over the bottom cutter-block C, which removes the dirt and takes off the roughness, comes to the fixed knives D D, which give the underside of the board a perfectly

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smooth surface; it then comes to the vertical cutter-blocks E E, which plane the edges, or rabbet and tongue-and-groove them; and finally passes under the top cutter-block H, which planes the top side. The timber is held down firmly on the bed by means of pressure weights.

For planing, flat straight-edged cutters are bolted upon the cutter-blocks; for working mouldings, cutters having their edges shaped to the required pattern are used in the same way.

The fixed knives D D are used on account of the difficulty of getting a perfectly smooth surface with a rotary cutter, when the timber is fed through the machine at so high a rate as is required for the working of flooring boards, which are planed with these machines at a rate of 70 ft. per min.; and this speed gives a smoother finish than a slower speed. These knives are fixed diagonally to the grain of the timber, in a drawer or transverse slide, which can easily be drawn out or pushed into the machine; so that when the fixed knives are not required, a plate can be substituted for the slide. The timber is held down upon the fixed knives by means of wheels fixed in a carriage, which receives its pressure from a weighted lever L through a universal joint, so that all the wheels press equally on the timber when its surface is uneven.

The side cutter-blocks E E can be moved nearer together or further apart by a hand-wheel and screw.

The top calender-rollers B are mounted on brackets, which swing on the axis of their driving wheel; so that when they are raised or lowered, according to the thickness of the material, the wheels keep the same depth in gear. These rollers are pressed down upon the timber by means of a weight K hanging underneath, which by means of a hand-wheel and screw M at the end of the machine can be raised so as to stop the feed.

The cutter-blocks are all driven direct from the countershaft N on the machine, in a direction opposite to that of the feed, at a speed of about 3000 rev. per min.

In Figs. 19 to 21, Plate 45, are shown an enlarged side and front elevation and a plan of the top cutter-block and headstock. The

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cutter-block H runs in bearings mounted on a bracket P, which is capable of turning on a centre J to bring the cutter-block to any angle with the horizontal line; so that in working architrave mouldings, as shown at A in Fig. 20, it is not necessary that the cutters working the lower side of the moulding should project so far over the edge of the block as to spring whilst cutting. The bracket P carrying the cutter-block is held at any required angle by means of a binding screw on the slide R, which can be raised or lowered by means of a hand-wheel and screw S, so as to regulate the depth of cut. The headstock is mounted on the table at an inclination, as shown in Figs. 17 and 19, so that when the cutter-block H is raised or lowered its movement nearly coincides with an arc of a circle concentric with the driving shaft N, thus keeping the strap at a more uniform tension than if the headstock were vertical.

The bearings used in this machine to carry the cutter-blocks are shown to a larger scale in Fig. 8, Plate 39. They are conical in form, which allows a high speed to be attained with less friction and vibration than in the case of the ordinary parallel bearings with collars. Through the centre of this bearing is screwed a steel pin T, so as just to touch the end of the spindle H, and thereby ease the pressure in the cone, so that it never exceeds the amount required for just keeping the spindle perfectly steady and preventing any vibration whatever in a lateral direction. This pin is turned less than the hole in the middle, to form a reservoir for oil; and is filed flat on one side at the end which touches the spindle, so as to allow a way for the oil to get to the bearing and thus keep it constantly lubricated. Spindles hung in bearings of this form are driven at as high a speed as 7000 rev. per min. without heating in the least degree.

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Mr. Robinson exhibited a cutter-block belonging to one of the wood-working machines described in the paper, carrying four cutters sharpened to a cutting angle of 25° (as shown in Fig. 4, Plate 38), that being a medium size for the cutting angle, which would do equally well for different kinds of timber, whether hard or soft. Another cutter shown was entirely for hard wood (Fig. 5), and was fixed nearly radially in the cutter-block, so as to cut almost at right angles to the timber, the cutting edge acting as a scraper, and being made with an angle of 60° so as to stand well. A tenoning cutter as an example of a cross-cutting cutter was also shown (Figs. 6 and 7), having the cutting blades C set so as to act diagonally to the grain, their edges being shaped slightly helical so as to have a continuous action. One of the slide-blocks carrying the saw in the horizontal saw-frame was exhibited (Figs. 14 and 15), showing the swivelling action of the guides on the top and bottom of the block, for enabling it to travel out of line along the inclined slide without binding. He also showed a specimen of the conical end-bearing (Fig. 8) used for the cutter spindle in the planing machine, and explained that the steel set-pin which eased the pressure in the coned bearing was filed flat on one side, at the end touching the conical spindle, so as to allow the oil to run down into the bearing and keep it constantly lubricated; it was immaterial whether the flat side got uppermost or undermost when the pin was screwed into its place, as in either case it ensured sufficient lubrication for the conical bearing.

Dr. Anderson considered that, notwithstanding the progress made during the past few years, wood-working machinery was still in its infancy. The earlier machines had had many imperfections, which was not to be wondered at, considering how slow this country had been to take up the subject. Attention had been first directed to it by Sir Samuel Bentham and the elder Brunel; and the ideas thrown out by those two great men, which were to be seen in all the tools referred to in the paper just read, had been more readily adopted and developed in America than in England. At the Exhibition of 1851 very little wood machinery

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was shown by this country, but a good deal from America, and it was then seen that England had not attached the importance to the subject which it demanded; considerable improvements had at that time already been made in the American machinery, and its simplicity and cheapness attracted much attention. The cutters shown in the drawings and in the specimens exhibited bore a great resemblance to those shown in 1851, not much progress having been made in respect either to the cutters themselves or to the means of fixing and balancing them; and it was to these points that he thought special attention should now be directed. The framing of the machines was now good enough; but the balancing as a rule was not perfect. There was no reason why, with the aid of lathes and by different modes of fixing the cutters, perfect balancing should not be attained, so that the rapidly revolving parts should run with absolute truth, without giving rise to any vibration whatever; the effect of the absence of vibration was very great upon the economy of working of any machinery and upon the quality of the work done.

With regard to the construction of the cutters themselves and the different means of fixing them, wood-working machinery in this country was at present very imperfect; in other countries better methods were being adopted, which he hoped would find their way here. In some of the French wood machines an entirely new plan had been adopted for preventing the cutters from being thrown off at a very high speed of revolution, by making the cutters themselves of very thin steel, such as was used for band saws; these thin strips were each bent round the circumference of a cylindrical cutter-block, like screw threads of very long pitch, and were held in their places by a series of segments or back-cover plates accurately shaped to fit the helical curve, leaving only the projecting cutting edge of the steel blade exposed to act upon the wood. With this mode of construction, however high the speed of rotation, there was no chance of the cutters being thrown off by the centrifugal force, the tendency of the helical cutters being to remain in their places.

Another feature in the same machines was the method of sharpening the cutters in their places by means of revolving emery

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wheels; this obviated the necessity of undoing nuts and bolts to get the cutters out for sharpening, and thereby reduced the cost of sharpening. Any work planed by these cylindrical cutters was therefore perfectly true, on account of the mode of sharpening. The same method was employed in the remarkable Swedish machines for cutting corks, which had been shown at the Vienna Exhibition in 1873. The cutting of cork was a difficult operation, and the cutters required to be constantly sharpened. In those machines, revolving emery wheels were provided close at hand, with which to touch up the cutters as frequently as required and while running, by means of a self-acting arrangement. In cutting from the rough, only just a touch was needed two or three times a minute, to keep the cutters perfectly sharp; and they then cut like lancets. For all other operations, such as cutting corks square and round and in pieces of special shapes, every cutter throughout the machines received a reviving touch between each cut, in order to keep it perfectly sharp.

With regard to the quality of the work produced by the cutting instruments in wood-working machines, this was very seldom perfect, as was seen even in the case of polished cabinet work, where the irregular surfaces left by the planing machine were very apparent, and most unsatisfactory to any one who knew what the work ought to be. In the best planing machine that he had seen, the wood after having been previously planed roughly by the ordinary revolving cutters was traversed on rollers underneath a vertical scraping tool, which was held down very rigidly upon it and adjusted so as to bring off a shaving so thin as to be almost transparent. The first shaving was imperfect, the second nearly perfect, and ultimately a perfect shaving was obtained at the third traverse. The scraping instrument had a reviver or revolving emery wheel attached, to keep its edge always sharp.

In band-saw machines the framing was now very good, and nothing better was required than the present construction of the machine as a whole; but the saws themselves were very imperfect, and it was necessary to go to another country for them. The steel of which they were made was sent from Sheffield to Valentigny, Doubs,

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in France, and came back to London made into saws, the price of which was very much higher than that of band-saws made in this country. That was not as it ought to be, and this matter of the band-saws was one to which the attention of mechanical engineers should be directed, because it was upon this and other points of detail, such as he had referred to, that the failure or success of wood-working machinery depended, as much as upon the general arrangement of the parts.

Mr. J. Shepherd thought that the helical cutter, which had been mentioned as of French origin, had really originated in this country, being the same as that used for cutting cloth, and also now used in ordinary lawn-mowing machines.

The President remarked that the question to be dealt with by the Institution was what was the best thing to use, not where was it invented. The lawn mower and the French helical cutter were doubtless the same thing mechanically.

Mr. J. Barrow, referring to the remarks made about having machines provided with arrangements for sharpening, mentioned that an arrangement of that kind had been carried out very successfully in a machine employed for cutting iron by means of a band-saw. Band-saws had been used with more or less success for about fourteen years past for the purpose of cutting iron, and the labour by which rough forgings were brought to their ultimate shape was very much reduced by that means. But the great difficulty in their employment for that purpose had been to sharpen them properly; and that difficulty had been so great as to lead to the abandonment of the band-saw at many works where it had been introduced. It had lately occurred to him to use a small steel worm, cut with a pitch double that of the saw, forming a sort of saw-file of circular shape, and to place this in front of the band-saw and make it revolve on a vertical spindle in contact with the saw, as a ready means of sharpening the saw and securing perfect parallelism of the teeth. That arrangement was now at work

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on a band-saw cutting iron at Messrs. Blair's marine-engine works at Stockton-on-Tees, the result being that the saw teeth having an equal amount of contact when cutting lasted much longer and did better work. There was a little difficulty with regard to the setting of the teeth: the saw at first being sharpened all in one direction acquired a tendency to "run" to one side in the work; but by making two worm cutters, one right-handed and the other left-handed, and running once round the saw with the right-handed cutter for sharpening half of the teeth, and then changing the cutter and running once round with the left-handed one for sharpening the alternate teeth having the contrary set, a sort of burr was formed on the saw, which just sufficed to give the clearance necessary for cutting the iron. Previously the saw had had to be taken off the machine every time it wanted sharpening, occupying a skilled workman for a couple of hours; but the sharpening now took only a quarter of an hour for each half of the teeth, and the whole operation was done without removing the saw from its place; the worm cutters were each $2\frac{3}{4}$ in. diameter. The saw was employed for cutting forgings of best iron up to 11 in. thick, shaping them to any form that was required; it was driven at a speed of 120 ft. per min. The sawing of iron had been first introduced about fourteen years ago in the gun-carriage department at Woolwich, where, owing to the substitution of iron in place of wood for the carriages, the wood-sawing machines would have been thrown out of use, had not some one very ingeniously placed spur wheels and pinions upon them and run them much slower, for the purpose of sawing iron plates; and they had been constantly in use there to the present time. He had no doubt that future improvements would be made, whereby much skilled labour would be dispensed with; and that the band-saw would come into important use for dealing with large forgings.

Dr. Anderson remarked that fine band-knives were used in some tailoring establishments for cutting out cloth, and received constant sharpening while employed upon the work.

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Mr. E. Reynolds said he was informed that at Messrs. Jessop's steel works in Sheffield they were rolling in considerable quantities strips for band-saws 80 ft. long, 5 in. wide, and No. 16 gauge (0·065 in.) thick. It appeared from this that the use of band-saws must have become extended to very large sizes.

Mr. E. A. Cowper, in reference to the use of saws for cutting iron, mentioned that many years ago he had introduced at Messrs. Fox and Henderson's works a circular saw to cut T iron and other bars for the construction of roofs, the ends being cut off cold by that means. The work was done much cheaper in that way than by forging, and when the saw was properly applied it was attended with great economy; the saw was sharpened by hand in a vice. The bars could be cut to any angle so truly as to require no forging whatever.

In America circular saws were used having loose teeth, which could be separately taken out for sharpening and put in again. A series of holes or recesses were drilled in the rim of the saw-disc, and the shank of each tooth being made with a dovetail was put into the hole and turned round, and was thus kept in its place. The teeth could be taken out and others put in, and the saw set to work again in a few minutes; the teeth were easily sharpened, and as they were all ground to exactly the same size the saw was always kept true in diameter.

With regard to planing machines, in large saw mills he had introduced an extra planing iron for superior work, with an extra pair of driving rolls to traverse the boards over it. By that means a very slight thickness of fine shaving could be taken off the surface, and the boards were finished with the best possible face.

In the manufacture of the wooden sash-bars of the roofing for the 1851 Exhibition building, a planed board was passed into a machine having a set of moulding cutters above and below the table, so that the grooves in the bars for putty, and the bevilling of the edges, were all done at once; and the board then passed a set of circular saws, which separated it at once into a number

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of sash-bars ready for use. These bars were painted by being immersed in a trough of paint, and drawn out through a series of fixed brushes, by which the superfluous paint was brushed off. The wood gutters were 5 in. wide by 6 in. deep, and had to be made with a bevilled gutter $2\frac{1}{2}$ in. deep along the top, and a slanting groove on each side to receive the condensed moisture from the inside of the glazed roof. The large quantity of wood to be removed in cutting out the gutter was more than could be done at a single operation; he had therefore employed a succession of three revolving cutters, each cutting deeper than the preceding. A piece of prepared timber 6 in. thick and 5 in. wide was fed into one end of the machine, and passed over the revolving cutters, which cut out the gutter on the underside; but at the same time, as two of the revolving cutters were set at an inclination, they cut an inclined channel along each side of the gutter bar, for catching the condensed moisture. The cylindrical mahogany handrails were made by first sawing them to an octagonal section, and then passing them through a hollow mandril with revolving cutters at its front end, one being a well-shaped wide gouge and the other a good chisel, placed on the wood so as to cut quite smoothly; the mandril ran at a very high velocity. Then to prevent the wooden handrail from being scratched and spoiled by the friction inside the mandril, there was attached to the framing at the back end a brass tube which projected right through the mandril and remained stationary, so that the handrail could slide freely through it without injury as fast as prepared by the cutters at the front of the mandril.

Mr. Jeremiah Head—referring to the limit of 9000 ft. per min. which had been assigned as the best speed for the circumference of a circular saw in cutting timber, on account of the blade springing under the extra strain brought to bear upon it by the increased force with which the teeth would strike the timber at a higher speed—remarked that it appeared to him if the saw was running perfectly true there would be no extra strain upon the teeth by driving it at a higher speed. For if the timber were fed against the saw at a

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constant speed, and the speed of the saw were doubled, it was evident the strain upon each tooth would be reduced to only half as much, instead of being increased; and in no case could more strain be put upon each tooth than the force necessary to sever the particular line of particles encountered by that tooth. If it were the case that practically the saw could not be made perfectly true, it was clear that it might be run up to a certain speed without the wobbling interfering with its steadiness; but higher than that speed it could not be run, and this seemed to him the only limit that would arise. How the particular limit of speed assigned in the paper—9000 ft. per min.—had been arrived at, he should be glad to know.

The conical bearing with end set-pin, used for the cutter spindle, as described in the paper, appeared an ingenious way of holding the spindle very steady in working; and he suggested that the same plan might be applicable with advantage to the back headstock of a lathe.

With the horizontal single-bladed saw frame he enquired what was the greatest length of saw-cut that could be taken in cutting veneers.

Mr. Robinson said that in the horizontal single-bladed saw the greatest depth of saw-cut that could be taken in cutting veneers would be 3-16ths inch. The machines were constructed of different sizes to take in timber of different maximum diameters; and timber had been cut up to 4 ft. width. The length of the saw was made as much more than double the length of the stroke as to give clearance to the timber on each side. The stroke was made longer or shorter according to the size of the machine.

The President enquired for what application this horizontal saw was intended: whether it was meant to be used for slabbing or for cutting a succession of boards, in lieu of the vertical saw frame carrying a number of saws and cutting many boards at once; or whether it was for making veneers. Supposing a log of mahogany were wanted to be made into boards, he asked whether this single-

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bladed saw would be preferred to the multiple frame containing as many as forty saws.

Mr. Robinson replied that the horizontal single-bladed saw was used either for slabbing or for cutting veneers. It cut veneers thinner than the vertical saw frame could do, because its cutting action was continuous instead of intermittent, and thinner saws could be used. The multiple saw he did not consider at all suitable for cutting veneers, because in cutting expensive timber like mahogany it might be necessary to examine the timber after each cut, in order to see how the grain was running or whether there were any knots, which could be done with this horizontal saw.

The helical cutter which had been referred to was used entirely for squaring up timber in readiness for planing, but was not employed for actual planing. In planing timber for doors or similar purposes, fixed knives were used for the finished surface on account of their greater speed of production. He had tried the helical cutter for planing, but had found it could not produce the work so quickly as the square cutter-block with straight-edged cutters. That was on account of the splitting action which came into play with the straight-edged cutters, enabling them to act partly as wedges in cutting off the chips of wood. The helical cutter was not so well adapted for that work.

As regarded fixing emery wheels on wood-working machines for sharpening the cutters, it was found well in practice to make the machines as simple as possible and keep them free from any complication, and not to trust to the intelligence of the men. Moreover the grit of the emery wheels would be liable to get into the bearings, which would be very injurious to machinery working at high speeds.

The American saw with separate teeth he had not seen, and he did not understand the advantage of having a saw of such a complicated construction, and thought there would be risk of the workmen leaving some of the teeth out. With the ordinary solid saws it did not take very long to remove the whole saw and sharpen

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the teeth one after another; there was then no possibility that any of the teeth might be missing.

With regard to the practical limit of speed for the circular saw, it was the fact that a saw did not run so steadily beyond a certain speed, because in practice it was impossible to make the teeth perfectly true; and acting as they did like a succession of wedges striking the timber obliquely, the more the speed was increased the greater would be the force of the blows, and the more liable it seemed to him the saw blade would be to spring. There was no other reason for the limit of speed being 9000 ft. per min. than the fact that this was found to be the best in practice for getting through the largest amount of work. If the saw ran either faster or slower it was found that the timber could not be fed so quickly as in running at that particular speed; and he should be glad to know of any theoretical explanation that could be given of this circumstance.

The PRESIDENT moved a vote of thanks to Mr. Robinson for his paper. In the discussion to which the paper had given rise, Dr. Anderson had stated the results of what he had seen in his travels; and he (the President) could not help thinking that one of the greatest uses of these meetings for the discussion of papers was seen when such information was furnished from observation of what was being done elsewhere. In the present instance ideas had been suggested which he had no doubt would receive due consideration from all interested in wood-working machinery.

The vote of thanks was passed.

The following paper was then read:—

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ON FLUID COMPRESSED STEEL AND GUNS.

By Sir JOSEPH WHITWORTH, Bart., D.C.L., F.R.S.

In the present paper the writer does not propose to enter into the consideration of the various chemical effects produced upon Steel, but to confine himself to what has a more immediate and practical bearing upon the application of steel as a constructive material. The difficulty he experienced in obtaining sound ductile steel led him to institute experiments in compressing the steel while in a fluid state.

For melting steel there are in operation at his works in Manchester the crucible, the Bessemer, and the Siemens-Martin processes; and pressure is applied to the fluid metal so melted, in each case, as quickly as possible after it leaves the furnace. The use of crucible steel for constructive purposes is being rapidly superseded by the metal produced in the Bessemer converter or the Siemens furnace; and although crucible steel is yet occasionally specified and demanded on account of its supposed superiority, yet its superior quality, when it exists, will be found to be due to the use of purer and better materials in its production; and if equally pure irons be employed in the other processes mentioned, a product is obtained equal in strength and ductility to crucible metal. Various specimens are exhibited of fluid compressed steel, which have a tensile strength of 40 tons per sq. in. The cylinders which have been burst by successive discharges of gunpowder do not, as will be seen, fly into pieces, but open out and tear like paper, as shown in Fig. 10, Plate 47.

In considering the question of "what is iron" and "what is steel," one of the first difficulties is the want of a strict definition distinguishing at once between wrought-iron and steel. A definition based upon chemical composition obviously fails to meet the

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requirements of the mechanical engineer; for two metals of analogous if not identical composition are known sometimes as wrought iron and sometimes as steel, according to the method of their manufacture. Similarly the definition based upon the hardening quality of steel is likewise objectionable, since the steel now employed for constructive purposes—as in the construction of boilers, guns, torpedoes, &c.—will not harden and temper in the usual acceptation of these terms. A piece of steel is exhibited which has been heated until just red and then quenched in cold water, under which treatment it has been strengthened, its tensile strength being increased from 33·83 tons per sq. in. to 46·77 tons per sq. in., and it still retained a ductility of 24·07 per cent., thus indicating an absence of that brittleness which is characteristic of hardened steel.

With so many rival and unsatisfactory definitions of steel, the writer would do away with all the different names by which various kinds of steel are known,—such as blister, shear, double shear, common steel, spindle steel, silver steel, cast steel, &c.,—which carry no precise definite meaning; and would express what is wanted to be known by two numbers, which should represent tensile strength and ductility. For whatever may be the purpose for which the steel is wanted, whether for purposes of compression or tension, if the engineer can give the steelmaker the strength and ductility, he will then be able to obtain with certainty what he requires. The writer would be glad if engineers after due consideration could agree upon some standard or list of ready application, according to which the metal should be designated as "iron" or "steel." Such a definition is to be found in an expression involving the tensile strength and ductility of metal, while avoiding reference to its chemical composition or method of production, for it is upon a combination of these two qualities (strength and ductility) that the value of the metal is dependent. He would suggest that the limit of tensile strength be taken at about 28 tons per sq. in., so that the metal exceeding this strength should be called "steel," while any description of iron falling below this limit of tensile strength should be known as "wrought iron."

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The power of elongation, represented by the word "ductility," is of the first importance for some purposes, as in guns, torpedoes, boilers, &c., and wherever severe strains might be suddenly applied; while in some cases, as in cutting tools, the strength of the metal is of the first importance. Cylinders of steel, to resist with safety the strains produced by gunpowder, should have a ductility of 30 per cent.: more than this is unnecessary, for cylinders of such metal do not fly into pieces when burst, but simply open out or tear like paper, and a metal of greater ductility would not therefore be required for any structural purposes. It is now possible to produce with certainty, by the compression of fluid metal, steel that will bear a tensile strain of 40 tons per sq. in., which elongates 30 per cent. of its length before breaking,—the length of the test recommended by the writer being 2 in. and its sectional area $\frac{1}{2}$ sq. in., Figs. 11 and 12, Plate 47; such a metal would not harden sufficiently to cut other metals.

Compressing.—The Mould Box for fluid compression, shown in Figs. 1 and 2, Plate 46, has an outer hoop of steel A A of the necessary thickness to withstand the pressure. The inside of this hoop is lined with a layer of cast-iron lags B B, from the front to the back of which are a number of grooves or channels, by which the gases can reach the outer face of the lags, between them and the inside of the steel box; while communicating with these transverse channels are made a number of vertical or longitudinal channels, which open to the atmosphere at I I at the top and bottom of the mould, and from which the escaping gases continue to burn for some time, when the pressure is applied to the fluid metal S S. The inside of the mould is finally lined with a layer of refractory sand, which, while protecting the cast-iron lags from fusion by the heat of the melted steel, also permits of the gases being driven through it by the pressure to the back of the lags, and so to the atmosphere. The core is built up similarly to the mould.

Dr. Tyndall, in a lecture recently delivered at the Royal Institution, said of this process witnessed by him:—"A large ladle was at hand, and into this was poured the molten metal from a number of crucibles. From the ladle again the metal was poured

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into the annular space just referred to, filling it to the brim. Down upon the molten mass descended the plunger of a hydraulic press. On first entering it a shower of the molten metal was scattered on all sides; but inasmuch as the distance between the annular plunger and the core on the one side, and the sheath on the other, was only about 1-10th in., the fluid metal was immediately chilled and solidified. Thus entrapped, it was subjected to pressure, which amounted eventually to about 6 tons per sq. in. Doubtless gases were here dissolved in the fluid mass, and doubtless also they were mechanically entangled in it as bubbles. I figure to myself the fluid metal as an assemblage of molecules, with the intermolecular spaces in communication with the air outside. Through these spaces I believe the carbonic oxide and the air to have been forced, finding their escape through the porous core on the one side and through the porous sheath on the other. From both core and sheath issued copious streams of gas, mainly it would seem in the condition of carbonic oxide flame. A considerable shortening of the fluid cylinder was the consequence of this expulsion of gases from its interior. The pressure was continued long after the gases had ceased to be ejected; for otherwise the contraction of the metal on cooling might subject it to injurious internal strains. In fact castings have been known to be rent asunder by this contraction. By the continuance of the external pressure, every internal strain is at once responded to and satisfied, and the metal is kept compact."

Forging.—The steel castings are forged by either the steam hammer, the rolls, or the hydraulic press, or a combination of these; but for large forgings generally there is a great superiority in the work produced by the hydraulic forging press. For the stroke of the press is that of a continuous pressure, and it is effective right through the mass of metal; whereas the blow of the steam hammer is largely expended within a short distance of the surface, while the centre of the work is for a certain period comparatively unacted upon, and therefore the different parts of the metal of the forging produced under the hammer exist in very different molecular

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conditions. This is not the case, as before stated, when the forging press is employed.

At the writer's works in Manchester will be seen a number of fluid compressed castings and forgings: one, a screw-propeller shaft, which when finished will be 18 tons weight, to supply the place of an iron shaft weighing 31 tons, thus saving the rotation of 13 tons during the life of the engine. Also numbers of hoops from 4 to 8 tons weight for 22 and 35 ton guns; also air vessels for torpedoes &c., and steel linings of various sizes for marine-engine cylinders, some 6 ft. diameter, 4 ft. 9 in. long, and 1⅝ in. thick.

Guns.—For Guns the writer has always advocated the use of steel, and steel alone. With this material field guns are forged solid, and afterwards bored and rifled, the trunnion hoop being screwed on; for larger guns the barrel is forged hollow, the strength and weight being obtained by adding hoops according to the size of gun.

When commencing to make guns on this plan for the Brazilian Navy, he determined that the test for the quality of the metal should be the explosion of gunpowder; and this test was of the greatest value at the commencement of the experiments with fluid compressed steel. The results of a series of experiments made in the year 1868 in testing by explosion of gunpowder are given in Table I appended, and these are very instructive. The experimental cylinders tested were each 4 in. length, 1¼ in. diameter, and ¾ in. bore, as shown in Figs. 3 to 10, Plate 47. No. 1 was a tube of cast iron, No. 2 of wrought iron, Nos. 3 and 4 of fluid compressed steel, and Nos. 5 to 8 were combinations of cast iron, wrought iron, and steel, as they have been used in different constructions of guns.

Specimens are shown of tubes made of fluid compressed steel that have been subjected to explosions of gunpowder. The large tube exhibited, 26 in. long, 7·83 in. diameter, with 2·56 in. bore, is that of a 9-pounder field gun; it has had 48 explosions with 1½ lb. of powder. The strain on the metal is about six times greater when the ends of a tube are closed than when a gun is fired in the ordinary way. The force of the explosion being so great, a small permanent

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alteration took place at the first explosion, and the expansion of the bore has been going on every time it has been fired, and now amounts to nearly 0·2 in. The experimental tube was never expected to stand such a number of explosions; and altogether 72 lbs. of powder have now been fired in it. A cast-iron tube of the same dimensions burst at the first explosion with 3 oz. of powder. A repetition of the experiments with the same compressed-steel tube will be shown at the works, by exploding 1¼ lb. of powder inside the cylinder, the ends being made up with the screw plugs; and it is surprising what little difference there is in the report from that of an ordinary gun, although the only escape for the generated gases is through a touch-hole of 1-10th in. diameter. Should the cylinder burst, there is not the slightest danger to be apprehended, for it will be inside a large steel hoop, 5¼ in. thick, and covered over with a strong steel slab. The writer is not aware that the material for the coiled hoops made at Woolwich for the monster guns has ever been subjected to a gunpowder test.

There is a controversy going on with reference to breech-loading and muzzle-loading guns. There will be an opportunity of examining at the works the writer's breech-loading gun; and he feels sure that the opinion will be in favour of breech-loading as against muzzle-loading. The results obtained have been far superior in every way to what is possible with any muzzle-loading gun. It may be mentioned that when rifled guns were first adopted in the service they were breech-loaders; but their construction and the comparatively weak wrought iron of which they were made only allowed, in the 7-in. bore gun of 4 tons weight, a charge of 14 lb. of powder, and the shot was 2 diameters long, weighing 110 lb. Such being the state of things at that time, the writer made a 7-in. bore muzzle-loading gun of 7 tons weight, with 22 lb. charge of powder, and a shot 3 diameters long, weighing 150 lb. This gun was consequently far more powerful than the service breech-loading gun of the same bore, and the War Department had other muzzle-loading guns made of the same proportions as regards weight and bore.

When fluid compressed steel proved so completely master of gunpowder, the writer at once saw that more powder might be fired

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from a breech-loader with a large powder chamber than could be consumed in a muzzle-loading gun. This 7-in. breech-loader fires 33 lb. of powder, being more than double the charge that is fired from the service breech-loader.

The following are some of the results obtained from the writer's breech-loading guns, as regards elevation and range, low trajectory, and penetration:—

At Southport in 1872, with the 9-pounder at 1 deg. elevation, the range was 1018 yards. The present service muzzle-loading gun at 2 deg. (being double the elevation) has a range only of 1065 yards.

A specimen exhibited shows the wonderful penetration of the field gun of 3-in. bore, the armour plate pierced being 4½ in. thick. In comparison with this result, in the trials made at Shoeburyness with the service 7-in. breech-loading gun and the 96 cwt. cast-iron 68-pounder, the experiments were carried on for about two years, without being able to penetrate this thickness of armour plate. It was in 1858 that the writer first penetrated 4½-in. armour with a solid shot; and in 1872 he first penetrated at Shoeburyness an armour plate with a steel shell, much to the astonishment of all the military men who witnessed it. If the War Department would now ascertain what penetration could be obtained from one of the present 3-in. bore muzzle-loading guns against a 4½-in. armour plate, a comparison could then be drawn between breech and muzzle-loading.

Guns of enormous size are now being made at Woolwich at an enormous expenditure; these guns must needs be powerful on account of their great weight and size, but the writer maintains that this enormous size is unnecessary. But if monster guns were wanted, they could be made at far less cost by means of the Siemens-Martin furnace and fluid compression. Supposing a hoop were wanted, say 20 tons weight, the time required for its production by this process, commencing with the raw material, would not, he believes, be more than one-tenth of the time required by the forging, coiling, and welding processes. Again, as regards quality of material, the use of

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good iron was given up at Woolwich some time ago, as it was found that weak poor iron was easier to weld and work than good iron. It is just the contrary with the Siemens-Martin or the Bessemer processes, in which everything is in favour of using good material; and the writer, wishing to convince the Admiralty and War Department of the superiority of his steel guns, particularly of the breech-loader, offered to lend them a 7-in. breech-loading gun, firing 33 lb. of powder, and also a 35-ton muzzle-loading gun which fires an armour-piercing projectile 5 diameters long, 1250 lb. weight, with a bursting charge of 58 lb.; but both these offers were declined, much to the surprise of the Brazilian authorities, from whom permission had been obtained to lend these two guns. The day of trial may be postponed by the making of enormous guns, which astonish and mislead the public; but it would be far better for an immediate trial to be made with the best guns of moderate size that can be produced. With strong, ductile, sound steel, the breech-loading gun, with its large powder-chamber, whatever be the size, must be superior to the muzzle-loader.

To prevent misunderstanding with reference to the weight of guns in relation to their bore, it may be stated that the writer has, for ship guns particularly, advocated greater weight for a given size of bore. The first 12-in. bore guns made at Woolwich were 23 tons weight, afterwards increased to 25 tons. In 1869 the writer submitted to the Admiralty a design for a 12-in. bore gun of fluid compressed steel, and he specified that the weight of the gun should be 35 tons, for he had always considered that (except for a mountain gun) there should be 105 lb. weight of gun for every pound of shot of 3 diameters length. It was however determined that the gun should be made at Woolwich, and the writer's weight for that size of bore was taken and has been adopted ever since.

With weak materials, there must be used weak powder, long guns, and short projectiles; but a strong, ductile, sound material allows of strong quick-burning powder, short guns, long projectiles, and rapid rotation. Long projectiles give greater penetration at both long and short ranges; also a much lower trajectory, except

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at the lowest elevations for very short distances. The iron plate exhibited illustrates what has been said with regard to the penetration of short and long projectiles; the projectile 2 diameters long has penetrated 0·5 in. deep, while that 3 diameters long has penetrated 0·8 in. In each case $2\frac{1}{2}$ oz. of powder was used and the distance was only 10 yards. If the distance had been more, the difference would have been proportionately greater, because the short projectile loses its velocity so much more quickly from its want of momentum.

In 1872, with the writer's 9-pounder breech-loading gun and a flat-headed projectile, a 3-in. armour plate was penetrated at an angle of 45 degrees. This form of projectile is also necessary for penetrating under water. A narrow strip of plating below the water line affords sufficient protection against round-headed or pointed projectiles, but it is useless against flat-headed ones. This will be seen on examining the plate exhibited, shown in Figs. 13 and 14, Plate 48, which has been struck by three shots fired through 80 in. of water, the point aimed at being placed at a depth of 10 in. below the surface. The flat-headed shot, Fig. 15, struck the plate at F, within about an inch of the level of the point A aimed at; while the round-headed shot, Fig. 16, struck at R, only $\frac{1}{2}$ inch below the water line; and the pointed shot, Fig. 17, struck at P, 9 in. above the water line.

In order to contrast the French Studded system adopted at Woolwich, and the Polygonal system, it may be stated that the twelve studs of a 9-in. projectile have a circumferential area of 18 sq. in. for supporting the shot, but the area of the sides of the six rear studs by which alone the rotary motion is given is only 1·6 sq. in. But no practical engineer would, if he could avoid it, provide so small a surface as 1·6 sq. in. for giving even a moderate amount of rotation to a body weighing 250 lb., much less when the rotation of the shot at the muzzle of the gun has to be at the rate of about 2500 revolutions per minute. In the 9-in. hexagonal projectiles the rifled surfaces which both support and rotate the shot have an area of 187 sq. in. Mechanicians are well aware

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of the importance of adequate bearing surface; and in the construction of machinery there has of late been a continual increase in the amount of bearing surface.

Another consideration of the highest importance in relation to the construction of artillery is economy of production. Polygonal projectiles for field guns are moulded by the writer's self-acting machinery, which gives a uniform density of sand in the mould, and ensures such perfect regularity in the size of the projectiles, that they can be fired as they are cast, as in the case of spherical shot in smooth bores. For projectiles of larger sizes, say of 150 lb. weight, suitable for a 7-in. gun, the two surfaces are planed at the same time, one by a broad-cutting tool ground to a straight line, the other by a hollow tool which rounds the circular portion; the wages cost of which is $2\frac{1}{2}d.$ Not only is there a considerable saving in the first cost of manufacture with polygonal projectiles, but they require less care and expense in transport, and can be used over and over again for practice. The ordinary studded shot and shell are far more costly, on account of the additional expense of preparing, fitting, and planing the studs. They also require great care in transport, and cannot be used after firing without being re-studded. A saving in the expense of ammunition is material, for it will be found that the cost of the projectiles fired from a gun during its life is commonly much greater than that of the gun itself.

One of the most important questions connected with ammunition is that of proper length of the projectile. A series of hexagonal projectiles are exhibited, beginning with the sphere, the others varying in length from 2 to 6 diameters. The writer ascertained in 1856 by experiment that a rifle bullet to give the best possible results should not be less than 3 diameters long; and this rule holds good whether for a 35-ton gun or for a rifle of the smallest bore. A longer projectile is heavier, its initial velocity is diminished, but its power of penetration is increased. It is true that the increased weight of the shot causes a greater strain upon the gun, thereby rendering it dangerous to fire long projectiles from weak

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and uncertain guns. Again, whatever be the windage, a polygonal shot must centre itself, and the effect of too much windage is merely a loss of propelling force; whereas in the stud system there is both a loss of force and an increased irregularity of motion due to the defective centering.

A projectile is exhibited having a conoidal front and slightly tapered rear, which the writer has proved by a series of experiments to be the best form for flight in all cases, the advantage increasing in proportion to the elevation. At the longest ranges this shot with its taper rear goes upwards of a mile further than one that is parallel. The best performance for range was obtained at Shoeburyness in 1870 with a Whitworth 9-in. muzzle-loading gun, namely 11,243 yards or 6·38 miles.

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TABLE I.

Testing of Experimental Cylinders by explosion of Gunpowder, showing the Comparative Strength of different Metals and of their combinations as used in the different systems of Guns.

No. of Cylinder.	Section shown full-size in Plate 47.	Description of Cylinders, Each 1¼ in. diameter, ¾ in. bore, 4 in. length. **C**ast Iron. **W**rought Iron. **F**luid Compressed Steel.	Charges of Powder.	Expansion in diameter before bursting.	No. of pieces when burst.
No. 1.	Fig. 3.	**C**ast Iron	Grains 15	0·0000	No. 36
2.	Fig. 3.	**W**rought Iron, Staffordshire coiled	95	0·0997	5
3.	Fig. 3.	**F**luid Compressed Steel, No. 3 Red†	275	0·1659	2
4.	Fig. 3.	**F**luid Compressed Steel, No. 3 Brown†	325	0·0950	4
5.	Fig. 4.	*Woolwich, Conversion of Cast-Iron Guns.* **C**ast Iron outside tube 0·1840 in. thick **W**rought Iron inside „ 0·0660 „	30	0·0010	**C** 14 **W** 1*
6.	Fig. 5.	*Parsons construction.* **C**ast Iron outside tube 0·1442 in. thick **F** No. 2 Yellow† inside „ 0·1058 „	80	0·0009	**C** 132 **F** 25
7.	Fig. 6.	*French construction.* **F** No. 2 Yellow† outside tube 0·0900 in. thick **C**ast Iron inside „ 0·1600 „	90	0·0020	**F** 20 **C** 71
8.	Fig. 7.	*Woolwich, present construction.* **W**rought Iron outside tube 0·2083 in. thick **F** No. 2 Red† inside „ 0·0417 „	140	0·3080	**W** 7 **F** 1*

† For explanation of these qualities of metal see Table II.

* The Wrought-iron tube in No. 5 and the Steel tube in No. 8 opened out in a single piece in bursting, in a similar manner to the steel specimen shown in Fig. 10, Plate 47.

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TABLE II.

FLUID COMPRESSED STEEL.

Tensile Strength and Ductility of different qualities.

Arbitrary distinguishing Colours for Groups.		Tensile Strength. Tons per sq. in.	Ductility, or percentage of Elongation.	Purposes for which the Steel is available.
		Tons.	Per cent.	
RED.	No. 1 No. 2 No. 3	40	32	Axles, Boilers, Connecting-rods, Crossheads, Crank Pins, Hydraulic Cylinders, Locomotive and Marine Cranks, Propeller Shafts, Rivets, Railway Tyres, Guide Screws, Gun Furniture, Gun Barrels, Air Vessels for Torpedoes, Carriages for Field and Naval Ordnance.
BLUE.	No. 1 No. 2 No. 3	48	24	Cylinder Linings for Marine Engines, Slide-bars for Locomotives, Shafting, Couplings, Lathe Mandrils, Drilling-machine Spindles, Eccentric Shafts for Punching and Shearing machines, Pillars for Hydraulic Presses, large Swages, Pressure-blocks for Riveting machines, Hammers, Hoops and Trunnions for Ordnance.
BROWN.	No. 1 No. 2 No. 3	58	17	Large Planing and Lathe Tools, large Shears, Drills, Smiths' Punches and Dies and Sets, small Swages, Cold Chisels, Screw Tools, Corn-mill Rollers, Armour-piercing Shells.
YELLOW	No. 1 No. 2 No. 3	68	10	Boring Tools, Finishing Tools for Planing and Turning.
Special Alloy with Tungsten		72	14	For particular purposes.

In each group No. 1 represents the most ductile metal, and No. 3 the least ductile.

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Sir J. WHITWORTH exhibited the iron plate referred to in the paper, and the three projectiles—flat-headed, round-headed, and pointed—which had been fired against it obliquely through 80 in. of water, the point aimed at being 10 in. below the surface of the water (see Plate 48). It was seen that the flat-headed shot (Fig. 15) had struck at F′ within about an inch of the level of the point aimed at (A, Fig. 14), having been scarcely at all deflected upwards by the water. The round-headed shot (Fig. 16), though aimed at the same point and entering the water at the same inclination, was deflected 9½ in. upwards so that it struck the plate at R, only ½ in. below the water line. The pointed shot (Fig. 17), which was the form now in general use in the service, was deflected still more, so that it did not even hit the plate below the water line, but struck it broadside at P, 9 in. above the water or 19 in. above the point aimed at. These results showed that in order for a projectile to penetrate in a straight line through water, without being deflected upwards, it must be flat at the head; and the best form was found to be one tapering very slightly from the middle towards each end.

He showed also specimens of the test bars (see Figs. 11 and 12, Plate 47) made of compressed steel of various qualities, which had been broken under tensile strains of different amounts; and also specimens of the small experimental cylinders (see Figs. 3 to 10, Plate 47) of 4 in. length, 1¼ in. diameter, and ¾ in. bore, which had been tested by gunpowder with the results given in Table I accompanying the paper. In the first experiment, a cast-iron cylinder (Figs. 3 and 8) was burst into 36 pieces by a charge of 15 grains of powder. In the second, the cylinder was made of Staffordshire iron coiled, and after several explosions with lower charges it was finally burst into 5 pieces by 95 grains of powder. The third cylinder was made of compressed steel of the quality which had the greatest amount of ductility, the power of elongation being 30 per cent., while the tensile strength was 40 tons per sq. in.; with 275 grains of powder it was expanded 0·1659 of its diameter and burst into only 2 pieces. This was the quality of metal that he considered most suitable for the manufacture of guns, torpedoes, and boilers. The fourth cylinder

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was made of compressed steel of a different quality, possessing a tensile strength of 50 tons per sq. in., with 20 per cent. power of elongation. It accordingly took 325 grains of powder to burst it, as compared with 275 grains in the previous experiment; but it expanded only 0·0950 of its diameter, instead of 0·1659, and went into 4 pieces instead of only 2; therefore, although so much stronger, it was not so ductile, and consequently not so safe. The long projectile exhibited, of 3 in. diameter and 15 in. length, which had passed through the armour plate (also exhibited) of 4½ in. thickness, was made of this metal, and was seen to be scarcely any worse for going through that thickness of plate, being only a little bent.

In the fifth experiment, representing the mode of converting cast-iron guns at Woolwich, the cylinder was made of an external cast-iron tube 0·184 in. thick, lined with a wrought-iron tube 0·066 in. thick (Fig. 4, Plate 47), these thicknesses being in the same proportion that was used in strengthening old cast-iron guns in this manner. The cylinder was burst with 30 grains of powder, and the cast iron went into 14 pieces, while the wrought iron opened out, expanding 0·001 of its diameter. The sixth cylinder, representing the Parsons construction of gun, consisted of a cast-iron tube 0·1442 in. thick, lined with steel 0·1058 in. thick (Fig. 5); it was burst with 80 grains of powder, the expansion being only 0·0009 of its diameter; the cast-iron went into 132 pieces, and the steel into 25. In the seventh cylinder, representing the French construction, the inside tube was of cast iron 0·16 in. thick, surrounded by an outside steel tube 0·09 in. thick (Fig. 6); it was burst with 90 grains of powder, expanding 0·002 of its diameter; the cast iron went into 71 pieces, and the steel into 20. The eighth cylinder, which represented the present plan of construction at Woolwich, had wrought iron outside, 0·2083 in. thick, and a steel tube inside, 0·0417 in. thick (Fig. 7). This was burst with 140 grains of powder, and the expansion was very good, being 0·308 of the diameter; the wrought iron went into 7 pieces and the steel opened out.

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Mr. J. Ramsbottom said he had been greatly interested in witnessing on several occasions the process now described of casting and compressing steel, and had been struck with the ingenuity displayed in carrying it out. To form a mould that would at once resist the very high temperature and pressure to which it was subjected, and would at the same time allow a free escape for the gases—which evidently did escape to a large extent,—was a problem of no ordinary kind, and had here been solved in a very satisfactory manner. Probably it was true, as had been remarked by Professor Tyndall, that a portion of the gases contained in the melted metal was absorbed by it under the extreme pressure in the mould, and disappeared in that way. On the other hand it was urged that, in the ordinary process of forging cast steel, these gases would be absorbed in the same way, though they might have formed cells in the original crude castings; and that the metal might even absorb from the cells carbonic oxide, which would disappear within its mass, as carbonic acid gas was absorbed by water under heavy pressure. Whether the gases were expelled externally or absorbed into the mass of the metal, one effect was evident, that the compressed steel when cast was sound and free from cells. This was apparently so when steel was dead-melted in the ordinary way, but practically it was known that it was not always so; and therefore there was at all events, in this method of compressing the cast steel in the mould, a means of securing with absolute certainty what was arrived at in the ordinary way only as a probability.

He quite agreed in thinking the time had arrived when it was necessary to abandon the idea of drawing any definite line of demarcation between what was iron and what was steel. The distinction between the two had gradually faded away, and the materials denoted by such common expressions as a steely iron and a very mild steel came so close together that he believed it would be very difficult for the most practical man always to say of a piece of metal whether it were iron or steel. It would therefore be a matter of convenience if the qualities of the different kinds of metal were expressed in definite language, in terms of the tensile strength and the power of elongation before fracture. Whether,

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when this was done, any such line of demarcation as had been suggested in the paper should be assumed for convenience, was an open question; but in ordering a material it would be a great convenience to be able to define exactly the character of the metal required in any particular case, because it was known how widely this varied at present under circumstances which seemed to be similar.

With regard to forgings of steel, whether compressed or otherwise, he had long been of opinion that it was difficult to have any steam hammer heavy enough for dealing with them. A blacksmith in drawing out a nail used a hammer very much heavier in proportion to the work than any of the steam hammers generally used for dealing with large forgings, the largest hammers being insignificantly small in relation to the work they had to do. There could be no doubt that the effect of compression by a hydraulic press was equivalent to that resulting from the blows given by a hammer of very greatly increased weight; under a continuous heavy pressure the inertia of the mass operated on was overcome, but that was not the case under the action of an ordinary hammer, because there was always some time occupied in the transmission of a blow to the interior of the mass, and the outside became more worked than the interior. This objection was lessened where the hammer was larger in proportion to the work; and where that was so, the work was always better and more effectually done. The hydraulic forging press accomplished the desired object mechanically; the only question was whether it did so with advantage commercially. When the cost of the work was a secondary consideration as compared with its quality, the press was the most effectual means of producing a very sound forging; but it sometimes happened that to aim at the best was to attempt what was impracticable, and when that was the case it was necessary to fall back upon the next best. In falling back therefore upon the steam hammer, wherever the press could not be employed, the larger the hammer was in proportion to its work, the more effectual would it prove, and the more satisfactory would be the forgings produced.

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As regarded the application of the compressed steel for guns, one thing was clear at the outset, namely that a sound material was better than an unsound one. With welds, the soundness was altogether a mere assumption; they might or might not be sound, and he was inclined to believe that a perfectly sound weld was an exception, the best being only a close approximation. It was impossible ever to be sure about the soundness; it was only known, when some accident had happened, that the weld had not been sound, as had so frequently been the case with the welded iron tyres formerly used on railways; and the safe remedy had been found in the substitution of the present weldless steel tyres. What was true of tyres was true of the welded parts of a gun. If it were possible to ensure the production of guns that could be absolutely depended upon for soundness, these must have a value which could never be attached to guns welded up of parts, whatever the quality of the iron employed.

Mr. C. W. Siemens observed that the paper now read was remarkable on account of the very striking results which had been arrived at, and which the members would have an opportunity of witnessing at the author's works. But perhaps the most remarkable feature of the subject was the systematic manner in which those results had been arrived at. The question of gunnery had been taken up by Sir Joseph Whitworth in 1854 in connection with the rifle, and in 1868 in connection with the construction of steel guns; and on the occasion of his reading a paper before the British Association in 1869 on the penetration of armour plates by long shells fired obliquely, the remark had been made by himself (Mr. Siemens), as President of the mechanical section, that "Mr. Whitworth having taken up the question of gunnery has viewed it from a mechanical point of view, and has arrived at purely mechanical results in this problem. His solution commends itself to all who have gone into the question; and it is natural there should be some diversity of opinion under such circumstances." The solution at that time arrived at by Sir Joseph Whitworth in connection with the question of constructing guns

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had reference to the method of rifling that he proposed; and it appeared to be conclusive. Nothing was more natural than that his attention should next be directed to the production of the material from which the gun was to be constructed; and having persevered in thoroughly investigating this portion of the subject, he had succeeded in arriving at the remarkable results brought forwards in the present paper.

In the plan now carried out, the steel after it had been produced was dealt with under a method entirely different from those before adopted, being here compressed while in a fluid or semi-fluid state. He had at first felt considerable doubt as to the effect of the new method. It was said that in applying hydraulic pressure upon fluid steel the gases contained in the fluid metal would be driven out; but he could not see how that was to be done by mere pressure. For in applying pressure to a fluid, the pressure acted in all directions equally; and why a particle of gas held in suspension in the fluid should go in one direction rather than another, and should get away from the pressure to which it was subjected, it seemed difficult to conceive. The facts however spoke for themselves; and these being ascertained, it was more easy to find an explanation of what took place. The result he suggested might be accounted for by the circumstance that the fluid steel congealing first on the outside of the mould offered more resistance there to the motion of the plunger, and the outside thus became comparatively speaking porous, while the fluid portion in the centre received a larger amount of compression than the outside which had more power of resisting the pressure. The particles of gas entangled within the fluid mass would therefore encounter rather less resistance towards the outside than towards the inside, the full hydraulic pressure being transmitted to the centre of the fluid mass. In that way the expulsion of the gases from the fluid metal might perhaps be accounted for; and he should be glad if Sir Joseph Whitworth would give his explanation of the matter. The fact being admitted, it was clear that the steel produced by that mode of treatment must possess many great advantages over metal treated in the ordinary way by hammering; for it was hardly

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to be supposed that hammering would be capable of driving out the gases.

With regard to the mode in which these gases entered the metal, he did not think they were merely entrapped mechanically at the time of pouring out the metal into the mould; because in working melted steel in the open hearth of a regenerative furnace he had found that the metal could be made at any moment to evolve gases in great quantities by simply plunging a cold bar of iron to the bottom of the fluid mass. The fluid metal evidently absorbed carbonic oxide to a very great extent; and it was due to the partial congelation of the metal that the gases were suddenly set free. Similarly in the Bessemer process a great ebullition took place on pouring the fluid metal out of the converting vessel into the iron moulds, and the top of the moulds had to be closed by a stopper to prevent the metal being thrown out by the ebullition. It was clear therefore that the metal contained a large quantity of gas occluded within itself; and if this was retained in the metal it became a source of weakness. However small the bubbles of gas might be, their presence would have the same effect as the presence of particles of foreign matter between the particles of metal, and must necessarily weaken it.

In reference to the proposal to designate as steel any metal bearing a tensile strain of 28 tons per sq. in., he thought it would be wise on the whole to fix a limit of strength, but some further limitation seemed also to be needed. For instance, a metal produced in the puddling furnace, with or without being converted into steel by the ordinary cementation process of making blister steel and shear steel, would have the required amount of tensile strength, and would therefore pass as a steel. But he considered a broad distinction should always be made between steel which had passed through the fluid condition and that produced by other processes, because the latter was deficient in one essential quality which was always sought for, namely uniformity of strength. He would therefore willingly accept the suggested definition of steel and iron according to tensile strength and ductility, if it were confined to metal that had passed through the fluid condition.

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It would appear from the paper that it was immaterial by what process the steel was produced, provided it had been produced from pure materials and would bear the required tensile strain. But however true it might be that the quality of the steel was due to its chemical nature, yet this chemical nature could only be obtained in a uniform and regular manner if the process of manufacture was in conformity with the conditions necessary to produce the desired result. Such steel he believed it would never be possible to produce by the old processes of puddling and cementation; and this led him to suggest that the demand for the qualities generally associated with steel should be confined to what was known as cast steel. The results of the experiments in testing small cylinders with gunpowder, as shown in the table accompanying the paper, were most instructive, and appeared to leave very little room for doubt that mild steel must be the proper material for the production of guns. Whether guns made of one block of steel like the old cast-iron guns, or those having an inner core hooped with steel rings, were the best, was a question for gunmakers to solve, and must depend mainly upon the dimensions of the structure. But the results now arrived at sufficiently showed what extraordinary strength and ductility combined might be obtained in constructing guns of a solid block of steel; and he hoped the Admiralty and the War Office would soon see their way to affording this system a thorough trial.

Mr. E. A. Cowper, referring to the condition of the gas in the fluid steel under pressure and the condition of the compressed steel after the pressure was removed, remarked that a certain quantity of gas must come from the sand lining, as in ordinary casting, some of which was carbonic oxide. Some of the gas however he thought still remained in the steel, and was accordingly subjected to the combined effects of the high temperature and heavy pressure in the mould. Supposing a very small cavity in the fluid steel were filled with this gas at atmospheric pressure, it would first be expanded about seven times by the heat of the melted steel, and then being put under the pressure of 6 tons per sq. in. or 900 atmos. would be compressed to 1-900th part of its size when heated; and in the

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subsequent cooling the pressure of the gas contained in it would be reduced again seven times, leaving it at a pressure of about 1920 lb. per sq. in. within an infinitesimally small bubble. The difference of the temperature of the gas when the steel was in a melted state and when it was cool was very great; and the difference of pressure was largely accounted for by the expansion of the gas, and it was possible it would be a very small speck when compressed under the hydraulic pressure of 6 tons per sq. in. He thought the gas must remain in this state in the steel ingot.

As there was carbon present in the steel, and it was almost impossible to avoid oxidising some particles of the iron in the Bessemer process, these particles were together in an ingot and would continue puddling after being run into the mould. The union of the carbon and oxygen of the iron formed carbonic oxide, causing the ingot to froth up in the mould, and producing a sponginess in the top of the ingot.

Mr. G. B. Rennie mentioned that about two years ago a trial had been made by the marine machinery department of the Admiralty of a compressed-steel liner supplied by Sir Joseph Whitworth for a large steam-engine cylinder of 55 in. diameter made by his firm for H. M. S. Amethyst, and according to the accounts he had received the wear was imperceptible. In consequence of the applicability of this system for making large shafts, a line of shafting had now been made of the compressed steel for driving the screw propeller in H. M. S. Bacchante, having engines indicating upwards of 5000 H. P.; and this shafting would be seen by the members at Sir Joseph Whitworth's works. By adopting the compressed steel a saving of metal of about one half had been effected in that line of shafting. It had indeed been originally intended to reduce the diameter of the shaft from 17 and 18½ in. to 16 and 17 in., which was considered sufficient for the work; but as there were a good many other dimensions dependent upon the size of the shaft, it was considered advisable to keep the outside diameter the same, merely diminishing the weight by having the shaft hollow. In reference to the application of the

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compressed steel to guns, it certainly seemed to him that a metal which it was so desirable to use for a shaft, on account of its great strength, must be of far more importance to be used for guns.

Sir J. Whitworth remarked that, when the pressure of 6 tons per sq. in. was applied to the fluid metal in the mould, a column of fluid metal of 8 ft. height was reduced 1 ft. in less than five minutes. No doubt there was a great deal of gas expelled during the compression, but he believed nine-tenths of it was common air; there was a portion of other gas mixed with the air, because it was burning while the pressure was on, but the greater portion he considered must be common air.

It had been pointed out that in casting ingots of steel in the ordinary way the metal was sometimes sound and sometimes not sound. His own experience had been that steel castings possessing 25, 30, or 35 per cent. of ductility or power of elongation, when pulled asunder were never found to be sound; with 10 or 15 per cent. of ductility an ingot might be sound through 3-4ths or 7-8ths of its length from the bottom end; but he had never got it sound when the ductility was higher. The great value of a metal lay in its tensile strength and ductility combined. The best metal for guns, torpedoes, and boilers was that which had a tensile strength of 40 tons per sq. in., and had also 30 per cent. of ductility. The effect of this was that when it was burst it simply opened out, and therefore there was no danger. There was never much more than 30 per cent. of ductility in the compressed steel; in Low Moor iron 40 per cent. was obtained, which was about the limit practicable. It was impossible to get both high tensile strength and high ductility, because as one was gained the other was lost. In the case of the metal having a tensile strength of 40 tons per sq. in. and 30 per cent. of ductility, these two figures together amounted to a total of 70; and it was a great achievement to get so high a total divided in such nearly equal amounts between the two qualities of tensile strength and ductility.

On first commencing the manufacture of fluid compressed steel, in order to prevent confusion as to the different qualities of metal

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he had called the softest metal red metal, the next in hardness blue, the next brown, and the next yellow; and each colour was subdivided into three numbers (see Table II). No. 2 Red had a tensile strength of 40 tons per sq. in. and 32 per cent. of ductility, the sum of these two figures amounting to 72. No. 2 Blue had 48 tons strength and 24 per cent. of ductility, giving the same total of 72. Perhaps No. 3 Blue or No. 1 Brown would be the right material for a sword blade, possessing high strength and fair ductility also. No. 1 Brown, having 50 tons tensile strength, was the material of the long shot exhibited, which had gone through the 4½ in. armour plate. No. 2 Brown had 58 tons strength and 17 per cent. of ductility, the two figures amounting to 75, which was a higher total than was obtained, except occasionally, from a very ductile material. Again, the group of metal denoted by Yellow, which was suitable for tools for boring and turning, had 68 tons tensile strength, but only 10 per cent. of ductility, the total being 78. It would be a grand thing if with the 68 tons strength 20 per cent. of ductility could be got, because such a metal would be tough as well as hard. A special alloy of this Yellow steel with tungsten gave 72 tons tensile strength and 14 per cent. of ductility, making 86 total. It was tensile strength and power of elongation properly combined which gave value to the metal; and as there did not seem to be the means of getting more than about 30 per cent. of ductility, whereas the tensile strength could be increased through an extensive range, the important object to be aimed at was to preserve the 30 per cent. of ductility and to get with it as high a tensile strength as possible, as that could never be too great.

Mr. W. Carpmael said he had seen in operation the process of compressing fluid steel, and certainly the apparent effect was that of squeezing the gases out of the metal; and looking at the porous character of the mould and the fact that its surface was covered with burning gases during the time of compression, he did not see much difficulty in believing that the gases really were expelled by the pressure: just as, if the mould were filled with wet sponges, there would be no difficulty in squeezing the water out of them in

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the same way. Or he thought the operation might be more properly represented by considering the steel as holding carbonic oxide gas in solution; this gas tended to escape as soon as sufficient pressure was applied, and where the fluid metal came against the sides of the mould it parted with the gas from its surface. The surface of the metal being thus purged from gas took a further supply from the interior portion of the mass, and parted with it in the same manner; and in that way he saw no difficulty in believing that the gas could be given off during the time that the metal remained in a liquid state under the pressure in the mould.

Mr. H. DAVEY suggested that the great increase of strength in the metal which had been compressed while in a fluid state might arise not from the air being squeezed out of the fluid mass, but rather from a different arrangement of the particles. For when steel was heated and immersed in cold water, the increase of strength thereby produced was very probably due simply to a different aggregation of the particles; and it seemed to him possible that, when steel in a fluid state was subjected to such a heavy pressure, it might in cooling assume a different molecular condition from that which it would assume under a much less pressure or under the pressure of the atmosphere only.

Mr. W. MATHER enquired whether the principle of compressing steel in a fluid state was also applicable to any other metal, and what had been the results of any experiments made in that direction. In mechanical engineering many difficulties arose in connection with cast iron, and he should be glad to know whether this could be treated in a similar manner and with similar results. There were many uses to which cast iron was applied, not requiring ductility or great tensile strength, but in which it appeared to have certain advantages over steel, possibly owing to its different chemical condition. If there were a probability that the application of the same principle of compression would improve the condition of iron castings and obviate the difficulty of blown castings, the prospect would be opened of a further field for the adoption of so valuable a plan.

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Mr. F. W. Webb considered the subject of the paper was a very interesting one, as he believed steel would be the most important metal in the future of this country. In reference to casting steel sound without pressure, he had found the "piping" and bubbles often met with in steel castings were due to a want of knowledge in putting together the moulds so as to provide for the escape of the gas without injury to the castings. Where the mould box was divided into four or five parts for making a long casting, if care was not taken to lute the partings in the mould as fast as the metal rose to the level of each parting, it was found that wherever the gas blew out there was a line of bubbles in the casting from the centre to the outside. At Creusot recently he had been very much struck with the magnificent ingots cast there from the Siemens-Martin furnaces, completely free from flaws, only a small head being left on the top, about 6 in. diameter and 4 ft. high; he had seen an ingot split, and there was not the slightest sign of honeycomb. The head of metal had a great deal to do with making sound steel castings. In 1872 he had shown at the Kensington exhibition a steel ingot cast at Crewe without pressure and perfectly free from honeycomb; that was done with a 4 ft. head, care being taken that the mould was perfectly dry and made of a porous non-conducting substance. Large steel shafts also had been cast partly to shape in moulds of a non-conducting substance, and had been so sound that he had seen them turned after forging perfectly bright and without a speck on their surface. For wheels, pinions, and housings, not requiring any forging, the addition of a little phosphorus was a great help in obtaining clean castings; if the steel contained 1-3rd per cent. of phosphorus it was much sounder than without it.

As regarded reducing the weight of shafting made of compressed steel, on account of the greater strength of this material in comparison with wrought iron, he remembered that when Krupp steel first came into vogue the endeavour had been made on one of the English railways to reduce the weight of the engines, by calculating to what extent the Krupp steel was better than wrought iron, and reducing the axles in proportion; but the consequence

was that the steel axles broke just as often as the previous wrought-iron ones had done. It was a mistake to reduce the axles to such a nicety, because the better and more expensive material could not then possibly have a longer life than the commoner material which it had replaced.

With respect to ductility, he had found no difficulty in getting mild cast steel that possessed as much as 33 or 34 per cent. of ductility, its tensile strength being from 30 to 32 tons per sq. in. He had made now 11,000 tests of steel boiler plates of this quality, by punching a $\frac{5}{8}$ in. hole in a strip 3 in. wide, and then driving a drift $1\frac{1}{2}$ in. diameter through the hole cold, without cracking the strip. This showed that it was possible to get a uniform quality of steel of high ductility. Out of 500 sets of steel boiler plates he had not had to condemn more than a single plate, and that was condemned through want of annealing; proper annealing was indeed indispensable for making steel boilers. The steel made at Crewe Works for the boiler plates contained 1-5th per cent. of carbon, the pig iron used being not too silicious; and it was considered a favourable sign if a little scull was left at the bottom of the ladle in casting the ingots. The exterior of the ingots showed a number of small air-holes; but when an ingot 18 in. square had been hammered, reheated, and rolled down into a plate $\frac{3}{8}$ in. thick, these surface defects disappeared practically, being reduced to a mere scale. After the shearing and punching was done, the plates were finally annealed before making the boilers; and he had never known an instance of failure with a boiler so made. For fireboxes, steel could hardly be tempered so low as was desirable, and he thought to use steel for the firebox with an iron shell was to begin at the wrong end; he considered it preferable to employ Bessemer metal made with ferro-manganese instead of spiegeleisen. However the steel boiler with steel firebox and tubes which had been shown at the Kensington exhibition in 1872 was still running; and not having heard of it since, he believed it was working all right. Five more fireboxes had been made with ferro-manganese, care being taken in all of them to keep the plates as thin as possible, on account of their being in contact with the fire, and to have no

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double thicknesses. The sides, back, and front of the firebox were a single plate, which for the largest firebox was 5 ft. 8 in. wide, 22 ft. long, and $\frac{5}{16}$ to $\frac{1}{4}$ in. thick; this was doubled up to the required shape, leaving only the tube-plate and top-plate to be riveted in, the thin plate under the tubes being flatted back into the water space to receive it. The firebox plates were made to a tensile strength of only 28 tons per sq. in., so that they were practically wrought-iron; after the first rolling they were immersed in a water tank 24 ft. long and 6 ft. wide, which was close in front of the rolls, and the plates became buckled up in every way; they were then reheated, this treatment being repeated four times. The plates appeared more like morocco leather all over the surface, and after shearing they were finally annealed, until they would stand bending double when cold without cracking.

Sir J. Whitworth said he had not made any trial of applying pressure to cast iron in a fluid state. It should be distinctly understood that the value of the process of compressing fluid steel under the heavy pressure employed was not in proportion to the ductility alone of the metal so produced, but consisted in obtaining high tensile strength in combination with ductility. He had himself never met with a sound steel ingot, cast in the ordinary way, that had anything like 30 per cent. of ductility; and he should be glad to know whether ingots forged simply as cast, and possessing that degree of ductility, had ever been cut in two and found free from air cells. Generally to get rid of air cells the pressure of 6 or 8 tons per sq. in. upon the fluid metal was sufficient, and in practice no higher pressure was used, in order to avoid subjecting the mould boxes to too severe a strain. He had however applied a pressure of as much as 20 tons per sq. in., in order to see what result would be obtained; and had found that with that amount of pressure the fluid compressed steel was rendered so perfect that it could not afterwards be improved by any process whatever, and needed no forging for any purposes. Instead of casting the fluid compressed steel in solid ingots, he considered it much preferable generally to cast it in the form of tubes, so as to afford

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greater freedom for the gases to escape from the inside surface as well as from the outside. No one had done more than Mr. Webb in connection with the use of steel, but it had been in dealing principally with boiler plates, rails, and axles, for all of which the cast ingots necessarily underwent a great amount of forging and rolling; and the soundness of the original ingots was therefore of less consequence in such cases.

Mr. F. W. Webb replied that the steel ingot which he had sent to the Kensington exhibition in 1872 was free from air cells and had been cast with a 4 ft. head.

Mr. G. F. Deacon thought it was impossible that expulsion of the gases from the interior could take place by compression while the metal was in the fluid state, because the pressure would be equal or nearly equal in all directions. The pressure it appeared was sufficient to reduce the ingot to 7-8ths of its original length, and it seemed to him that the expulsion of the gases so far as it was due to compression must really commence with the process of congelation, and that it took place by reason of the same kind of action that had occurred in certain rocks in which planes of cleavage having no relation to stratification had been produced by compression. Supposing such planes to form at right angles to the direction of pressure during the process of congelation, the bubbles of gas would be flattened, and joining each other would find the least resistance in a horizontal direction; thus after the commencement of congelation, but not before, there would be some analogy to squeezing water out of a sponge. If that view were correct, it would suggest the possibility of there being a certain amount of lamination in a mass compressed in one direction in this manner, after the commencement of congelation and during the lateral expulsion of the gases. He should be glad to know whether there was not some difference in the tensile strength of the metal in the two directions, at right angles and parallel to the direction of pressure; if so, the greater strength being round the gun would be in that direction in which it was most required.

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Mr. D. ADAMSON considered the results of the process of compressing steel in the fluid state, as described in the paper, were most interesting and valuable; and he thought the soundness of the steel ingots so compressed could be sufficiently accounted for on mechanical principles, without having recourse to any explanation involving chemical action for the expulsion of gases. For it was impossible to get a solid ingot in casting in an ordinary iron mould; the metal in running into the mould must necessarily become cooled and solidified on its outer surface first, and by its contraction caused the metal to boil out at the top after being run, the centre still continuing fluid. But as soon as the ingot had become solidified and fixed at the circumference and at the ends, there was no longer any possibility of getting it solid in the centre. The outer surface being solidified, the natural contraction of the metal in cooling must leave some vacuous pores. The metal was then no longer of a weldable character, and however solid it might be made to appear by subsequent hammering, the mass was not thoroughly united, particle to particle, but only mechanically closed together. The difference between the tensile strength and ductility of the compressed steel was explained on that basis, the compression taking place during the time that the outer surface was becoming solidified, and thus the whole mass was made really solid. In Sheffield he believed it had long been understood amongst the makers of cast steel that in order to get a solid ingot a stick of pine wood should be held in the centre of the melted steel in the mould, and lifted out just when the metal was setting; by this means the centre portion was kept liquid to the very last, and enabled to set with a better chance of being solid; and he understood the same plan had many years ago been found by Mr. Mushet most efficacious in preventing the metal from becoming separated at the centre. The steel made at Crewe, possessing a tensile strength of about 30 tons per sq. in. with 30 per cent. of ductility, was no doubt entirely satisfactory for the purposes for which it was employed; but the great point was that in the compressed steel with the same ductility the tensile strength was increased to 40 tons, on account of the particles being really welded together in the interior of the mass.

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With this metal for the plates of ships there would be a great reduction in weight, allowing of a corresponding increase of cargo.

Whether or not the same operation of compressing the metal in a fluid state would be equally applicable to cast iron, it was certain that the cause of unsoundness in iron castings was the same as with the steel ingots. When an iron casting was of varying thickness, the metal was never so solid at the thick as at the thin parts; the outer surface having been chilled in the mould solidified first, and caused a porous interior by preventing the inside particles from coming close together in cooling. In large cast-iron shafts and other similar heavy castings the metal was never so close in the centre as at the outside. The cause he considered was purely a mechanical one, having nothing to do with any presence of gas.

High-class iron seemed often to be spoken of as a material necessarily possessing great elasticity in addition to great tensile strength; but this he thought was altogether a mistake, and he agreed in considering that high tensile strength was a property incompatible with high ductility. Low Moor iron, for instance, although it was a most reliable material on account of its great ductility, and would consequently last for many purposes even better than compressed steel, had not a high tensile strength but only high elasticity; and those kinds of steel which were most elastic were all of a mild character and low tensile strength. Steel that contained more carbon was denser and possessed a higher tensile strength; but it was not more reliable on that account, because its ductility was not increased in proportion to its power of endurance under a tensile strain.

Mr. H. Sharp observed that in the ordinary mode of casting Bessemer steel ingots, by pouring the metal into open cast-iron moulds, there was no doubt perfectly solid ingots could not be obtained. But he had seen many Bessemer ingots which had been cast under the pressure of a head of metal of from 4 to 5 ft. height, which were perfectly sound; and in making large castings for

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forgings, the plan he adopted was to use a loam mould and give the casting a head of the height named, by which means the portion required for the forging would be perfectly sound and free from honeycomb. Although these castings were not made under such a pressure as the steel made by Sir Joseph Whitworth's process, still they were very strong. The ductility of the steel in the ingot he had not ascertained, all the tests having been made after forging it or rolling it into plates; in this state it was found to have a tensile strength of 33 to 34 tons per sq. in., with 20 to 25 per cent. extension before breaking, the trial pieces being 6 in. long, and stretching $1\frac{1}{4}$ to $1\frac{1}{2}$ in. before breaking.

Mr. C. COCHRANE was somewhat surprised to learn that the ingot of fluid compressed steel was reduced in bulk to the extent of so much as 1-8th by the pressure put upon it in the mould. This he thought could not all be owing to expulsion of the gas, as he could not imagine the ingot had originally contained so large a quantity of gas. It appeared to him the reduction would partly be due to the expansion of the heated mould, which must be materially increased by the very heavy pressure; but how much would thus be accounted for, it was difficult to say. To some extent the result of the compression seemed to be more of the nature of prevention than of cure: the gas between the molecules, being compressed to 900 atmospheres, would be further dissolved in the steel, but what was not so dissolved would be prevented from escaping.

Mr. E. REYNOLDS remarked, in reference to the application of the process to other metals than steel, that the system had been extensively used in copper works for the last twenty years at least; this however did not detract from the merit due to the successful application of a difficult process. He could confirm the statement that perfectly sound steel ingots were produced, though perhaps not so regularly as could be desired, without any greater pressure than the usual head of metal: one necessary condition being that the steel should be, as had been said, "dead-melted." If it were not so, the steel would "rise" in the moulds, as was very commonly the case

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with Bessemer metal, from the evolution of gases within the metal. It was common to "stopper" Bessemer moulds, in order forcibly to confine this rising within small limits; and considering how small a force was sufficient in this instance to resist an apparently powerful agency, it was easy to understand that a greater force applied by a press might wholly prevent the internal evolution of gas, and to conceive that it might cause the re-absorption of such as might be partially developed.

But good work might be done, without the use of a press, by "dead-melting;" and it was desirable to trace the nature and effect of this. In melting by the crucible, it was not sufficient to get the material well heated and thoroughly fluid; but after it had arrived at that condition it must be left for some time in the furnace to "kill" it. In a lecture upon fuel, delivered by Mr. Siemens at the Bradford meeting of the British Association, attention had been called to the remarkable discovery that there was a limit to the heat at which combustion was possible; and that this limit, at which oxygen and hydrogen might be mixed without burning—which it had been proposed to call the heat of dissociation—had been fixed by M. St. Clair Deville at about 4500° Fahr. The application of the same principle to the combination of oxygen with carbon, silicium, &c., appeared to furnish an explanation of the nature of "dead-melting," which might assist in the more general production of sound ingots. In the ordinary methods of steel-making a great heat was obtained, and in the Bessemer process the heat was still greater; so that in either case a near approach to the heat of dissociation was soon reached, and chemical action was arrested before being completed. But if the metal were cast in that state, it would soon cool down to a temperature at which chemical action would again come into operation; and gases would be evolved, giving rise to honeycombing. The remedy was to keep it melted for a considerable time, so that the chemical action, which was then very languid from the near approach to the heat of dissociation, might have time to become complete.

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An instructive illustration of this principle was afforded in the working of the regenerative tank furnaces for steel-making. If these furnaces were worked at too low a heat, the charge would become softened so rapidly that the metal would set (soft steel having a high melting point), and much time and patience and a great heat would be necessary to remelt it; and inasmuch as the intense chemical action, due to a low heat, applied to the furnace as well as to the charge, the slag would run into the sand bed of the furnace as into a sponge, and when remelted probably a considerable part of the charge would leak out. This made it necessary to take from ten to twelve hours for a process which might otherwise be completed in three or four hours, and to use a very high heat in order to avoid cutting the furnace to pieces. The fact which had been mentioned, that if an iron bar were put into the melted metal in the furnace it caused gas bubbles to arise, was he thought because the temperature was thereby lowered sufficiently for the chemical action to recommence; and if it was attempted to rabble the metal, an excessive ebullition was caused.

When steel really dead-melted was cast into a mould, it naturally cooled first on the outside; and the inside having to contract afterwards, a cavity was left in the centre of the upper part, which was called "piping," the remainder of the ingot being sound. Though in the present state of the manufacture the system of compressing the metal whilst fluid might be the most certain method of preventing the recommencement of chemical action, and might therefore be of great value for the highest class of work, its legitimate function ought to be confined to forging down the metal whilst cooling, and so reducing the loss by piping. Any apparent increase of strength he believed would be found to be the result of the forging action; and if the ingot was sound, it would be equally obtained by forging it afterwards in the usual manner.

Mr. C. W. Siemens concurred with the remarks of Mr. Reynolds respecting the dissociation that took place at the high temperature which existed in a steel-melting furnace. He added that, on putting a cold bar into the fluid metal in the furnace, the ebullition took

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place only during the earlier part of the process; after the steel was completed and spiegeleisen or ferro-manganese was added, no ebullition was caused by the insertion of the bar, showing that at that period of the process the point of "dead-melting" had been reached.

Mr. F. Preston mentioned that an illustration of the importance of getting rid of the air, for obtaining good castings in steel or iron, had been afforded at a foundry where there were three cupolas, one of which was never successful in making good castings, and in running the metal the gas was always given off like fireworks. On taking this cupola down, it was found that it had been erected on masonry with a large circular cast-iron bed-plate upon the top, 3 or 3½ in. thick, forming the bottom of the hearth. The reason of the previous difficulty was then obvious; the plate had prevented the air from escaping through the bottom of the hearth, and it was as necessary that the air should have vent when melting the iron as when making a casting. The cupola was afterwards rebuilt without the iron plate, and then produced iron like that from the two other cupolas; the plate had been the only cause which had prevented the air escaping at the base, and after its removal the escape was so strong that the gas could be lighted.

The adoption of a porous mould lined with loam for casting the ingots of fluid compressed steel was in accordance with the universal experience in making large moulds for ordinary castings. In a moulding shop not only was ample provision made for the escape of the air from the mould through numerous vents, but a straw or hay bed was made for the mould to rest upon, in order to give further facility for the air to escape through the bottom of the mould. If the same attention were given to casting steel ingots as in making ordinary castings, it would be found that the air would be got rid of far better than by casting in iron moulds; but if an iron mould was lined with ganister, the principle of a porous mould was better carried out. Another great objection to the usual mode of casting the ingots was that the iron moulds were set upright, with the broad end forming the base to stand upon, which prevented the

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gas from escaping freely; the moulds ought to be set with the wide mouth upwards, to encourage the gas to get away.

Some experiments had been tried for casting in a vacuum, by connecting an air-pump with the mould, and starting it to work as soon as the running of the metal commenced, so as to aid in getting rid of the gas; and it would be interesting to hear the result of that plan.

Mr. F. W. Webb said the trial made of casting in a vacuum had been successful as regarded the production of a vacuum, for the pipe connecting the air-pump was pumped full of steel; but it did not result in a sound ingot. The idea was brought out eight or nine years ago by Messrs. Lüthy and Bell at the Bolton Iron and Steel Works.

Sir J. Whitworth mentioned that his first experiments on the use of fluid compressed steel for guns had been made by subjecting the material to a gunpowder strain, using small tubes like the specimens shown (see Figs. 3 to 8, Plate 47), and measuring the strength of the metal by the number of grains of gunpowder required to burst the tubes; as many as 3000 of these tubes had been burst experimentally in that way. Now however he had entirely given up that mode of testing, and had adopted in preference the more definite test of tensile strength and ductility, by pulling asunder small test bars of ½ sq. in. sectional area, like the specimen exhibited (Figs. 11 and 12). In order that the information thus obtained, of which the average results were given in Table II, might be compared with the general strength and ductility of iron, he had made a series of similar experiments with the principal kinds of wrought iron and cast iron, of which the following were the results, including the purest and best iron that was made in England:—

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		Tensile Strength. Tons per sq. in.	Elongation. Per cent.
Wrought Iron	Yorkshire	31	23
		30	22
		29	31
		27	41
		27	22
		26·8	43
		26·8	42
	Low Moor	27	39
		24·8	42
	Northamptonshire	27	39
		26·8	40
		26	41
		25	38
	Staffordshire	25	35
		24	39
		24	34
		24	33
		20	15
	Staffordshire (Dudley Ward)	26	30
		24	35
		24	28
Cast Iron		13	0·90
		12	1·10
		11	1·00
		11	0·65
		10	0·75
		9·5	0·12
		7	0·50

With regard to annealing, in the manufacture of Krupp steel more carbon was put into the metal than the steel was intended to have ultimately, in order to get it sound, and all the forgings were afterwards subjected to a long process of annealing, which was very necessary on that system. But with the fluid compressed steel all the large forgings were completed without ever being annealed afterwards; the metal was right already, and required no annealing.

The President said he entirely agreed with the observations that had been made by Mr. Adamson in reference to the very interesting subject brought before the meeting in this paper by Sir Joseph Whitworth, to whom he moved a vote of thanks for the paper, and

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for having come among them on the occasion of their visit to this city, to which he had added lustre by his extraordinary researches. His valuable paper had given rise to one of the most interesting discussions that had taken place in the Institution.

The vote of thanks was passed.

The following votes of thanks were then moved by the President and passed :—

To the Mayor of Manchester, for so kindly granting the free use of the Rooms at the Town Hall for the Meeting of the Institution.

To the Local Committee, the Chairman Mr. Robinson, the Deputy Chairman Mr. Wren, the Honorary Local Secretaries Mr. Hetherington and Mr. Hutchings, and the City Surveyor Mr. Lynde, for the excellent arrangements they had made for the Meeting.

To the Directors of the Society for the Promotion of Scientific Industry, to Mr. Reilly, and to Mr. Robinson of Rochdale, for their very kind and handsome reception of the Members on the occasion of the Meeting.

To the Proprietors of the several Works visited during the Meeting, for their kindness in opening their works to the Members; and to the Railway Companies, for the special facilities and privileges granted for the Excursions.

In the afternoon the Members visited the works of Sir Joseph Whitworth and Co., where they witnessed the testing of an experimental cylinder of fluid compressed steel by exploding in it for the forty-ninth time $1\frac{1}{2}$ lb. of gunpowder, the only escape for the gases being through a vent $\frac{1}{10}$ inch diameter; after these tests the cylinder although slightly enlarged remained perfectly sound. A specimen of fluid compressed steel was also tested under

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a tensile strain of 40·8 tons per sq. in., at which strain it was pulled asunder with an elongation of 32·7 per cent. A number of specimens were shown of the various descriptions of engineering work, guns and projectiles, made of the steel, including the large screw-propeller shaft referred to at the meeting. The mould boxes and hydraulic presses employed for compressing the fluid metal were shown, together with the hydraulic forging press taking the place of the steam hammer, and also the hydraulic lifting tackle traversing overhead for handling the casting ladle and the forging work.

The Members visited the Mayfield Print Works and the Broughton Copper Works; and the following Works were also opened to their visit:—

Ashbury Railway Carriage and Iron Works.
Collier and Co.'s Tool Works.
Craven Bros.' Tool Works.
Crossley Bros.' Machine Works.
Curtis Sons and Co.'s Cotton Machine Works.
Dodge and Co.'s File Cutting Works.
Hetherington and Sons' Cotton Machine Works.
Johnson's Wire Works.
Mather and Platt's Tool Works.
Andrew Muir and Co.'s Tool Works.
William Muir and Co.'s Tool Works.
Nasymth Wilson and Co.'s Bridgewater Foundry.
Ommanney and Tatham's Foundry.
Railway Steel and Plant Works.
Sharp Stewart and Co.'s Locomotive Works.
Smith and Coventry's Tool Works.
Wadkin and King's Cotton Spinning Mill.
Wren and Hopkinson's Tool Works.

In the evening the Members were entertained at Dinner at the Royal Exchange, by the Society for the Promotion of Scientific Industry. Afterwards the Newspaper Printing Offices were opened to the visit of the Members, and the printing machinery was seen at work.

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On Thursday, 29th July, an Excursion was made by the Members by special train to Hyde, Oldham, and Rochdale.

At Hyde Junction, Messrs. Adamson's Engineering Works were visited, where a number of steel and iron boilers were seen in manufacture, with the rivet holes all drilled after the bending and fitting of the plates. The process of flanging the flue plates by rolling was seen, and the welding of boiler flues and shells by means of steam hammers, and the welding of conical tubes in the flues. Various steam engines were in course of construction, including a pair of vertical direct-acting blowing engines with 72 inch blowing cylinders. In the two adjacent cotton mills of the Newton Moor Cotton Spinning Co. were seen the triple and quadruple horizontal compound engines constructed by Messrs. Adamson for driving the whole of the machinery. The first, erected in 1862, has three cylinders on the same piston-rod, the diameters being 16, 22, and 38 in., and the stroke 6 ft.; the steam enters the first cylinder at a pressure of 80 lb. per sq. in., and the third cylinder at about atmospheric pressure; the engine makes 33 rev. per min., and a second similar engine is coupled at right angles, the pair driving about 670 Ind. H. P. The other engine, erected in 1874 and driving about 550 Ind. H. P., has four cylinders, in two pairs coupled at right angles; two cylinders are on each piston-rod, the first two 17 and $22\frac{1}{2}$ in. diameter, and the second two $30\frac{1}{4}$ and 42 in.; the stroke is 5 ft., and the engine makes 43 rev. per min.; the initial steam pressure is 96 lb. per sq. in. in the first cylinder, and about 1 lb. in the last, the vacuum in this cylinder being 12 lb. per sq. in.; the steam is superheated in its passage from the second to the third and from the third to the fourth cylinder by means of a casing filled with fresh boiler steam.

Messrs. Bradbury and Co.'s Sewing-Machine Works at Oldham were then visited, where every operation in the manufacture of sewing machines was shown, from the metal casting and the sawing up of the logs of walnut and mahogany, to the silver and nickel plating and ornamenting of the finished machines. The sewing machines are made with the whole of the parts constructed

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upon the interchangeable system, and exact duplicate work is ensured by a number of special tools.

At Messrs. Platt Bros. and Co.'s Works at Oldham the manufacture was seen of the various descriptions of machinery used in cotton spinning and cotton and woollen manufactures; one room alone in the works contained as many as 300 lathes in full operation, boring, turning, and planishing the various descriptions of work, several of them being 4-spindle lathes, operating simultaneously upon four sets of wheels, pulleys, &c. In the loom-making shop the loom frames are erected and fitted up complete, the woodwork required in their construction being prepared in an adjoining shop. In the forge, crank shafts up to $1\frac{3}{4}$ in. diameter are shaped hot by three blows of a steam hammer with successive dies; the shafts for the spinning machinery are straightened in a machine having three rollers, between which the shafts are made to traverse. The rolling-mill engine of 100 H. P. drives the roll trains through a leather belt 34 in. wide, made up of three widths. In the moulding and casting shop a large number of moulding machines are employed for producing the great variety of small spur and bevil gearing required in large quantities; the casting ladles and mould boxes are conveyed through the shop by hydraulic cranes. At these works was seen still in use one of the first steel boilers made in this country; it is constructed of Howell's homogeneous metal, and has now been seventeen years in work, at a pressure of about 70 lb. per sq. in. In the brickmaking department the manufacture of dry-clay bricks was seen in full operation with the pair of stamping presses described at a previous meeting (see Proceedings Inst. M. E. 1859 page 42); in continuous working five million bricks are produced per year from each press, and these are wheeled direct from the press into the kiln for burning, no previous drying being required. The Members were invited to refreshments at Messrs. Platt's and Messrs. Bradbury's Works.

At Messrs. Robinson's Wood Machinery Works at Rochdale a great variety of wood-working machines were seen in operation,

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including the planing and moulding machine and the horizontal single-bladed saw described in the paper read at the meeting, and also the American dovetailing machine described at a former meeting (see Proceedings Inst. M. E. 1868 page 81). The manufacture on an extensive scale of doors and window frames and other joiners' work was seen; as well as the manufacture of the various wood-working machines, which are here made in large numbers, and fitted up complete with the driving engines ready for use. The Members were entertained at luncheon in the Town Hall, Rochdale, by Mr. John Robinson.

On returning to Manchester in the evening the Members visited the New Town Hall works in progress and partly completed, containing all the municipal offices, including those of the Corporation Water works and Gas works, and extending over an area of 359 ft. length and 326 ft. width.

On Friday, 30th July, an Excursion was made by the Members by special train to visit Messrs. Beyer Peacock and Co.'s Locomotive Works, and the Locomotive Works and Steel Works of the Manchester Sheffield and Lincolnshire Railway at Gorton; also the Manchester Corporation Water Works at Woodhead and Hadfield.

At Messrs. Beyer Peacock and Co.'s Locomotive Works the whole of the shops are on the ground floor, and are so laid out that the main portion of the work may pass forwards in its successive stages from one shop to the next, with the least possible expenditure of labour in shifting it from place to place; branches from a railway siding are also laid into every part of the works. In the machine shops the shafting is driven by a number of independent pairs of engines of locomotive construction, fixed vertically against the walls. A large number of locomotives were seen in various stages of construction.

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At the Manchester Sheffield and Lincolnshire Railway Works, the locomotive, carriage, and wagon shops were seen; and the Bessemer steel works, where the special heating furnaces were seen, constructed with a forced draught obtained by steam jets.

The Members then visited the Manchester Corporation Water Works storage reservoirs in Longdendale; a description of these works was given at a former meeting of the Institution by the Engineer-in-Chief, Mr. Bateman (see Proceedings Inst. M. E. 1866 page 245). The area of drainage ground from which the water supply is obtained is 19,300 acres or 30 square miles, and the area of the storage reservoirs 600 acres, with a total capacity of 4,590 million gallons. The Woodhead reservoir, which is situated 18 miles east of Manchester, near Crowden Station, is the most distant, and is at a height of 780 ft. above sea level; its area is 135 acres, and the greatest depth of water 72 ft., the storage capacity being 1,235 million gallons. The embankment forming this reservoir is 90 ft. high from the bottom of the puddle wall, and the wall was carried down into ground that was believed to be impervious to water; but after the filling of the reservoir this was found not to be the case, a gradual leakage of water making its way underneath the bottom of the puddle wall, thereby endangering the safety of the bank when the reservoir was filled more than 55 ft. deep. In order to secure the top water capacity it became necessary therefore to construct a fresh embankment immediately outside the original one, carrying the new puddle wall down 50 ft. deeper through the debris of the millstone grit into the solid shale beneath; so that the total height of the new bank, now nearly completed, is from 140 to 160 ft., the puddle wall being concreted to a thickness varying from 23 ft. to 7 ft. The water is discharged from this reservoir into the next below by pipes 48 in. square laid through a tunnel driven in the solid hill at the end of the embankment. The sluices closing the pipes are worked by a turbine of 12 in. diameter situated at the bottom of a well 141 ft. deep, the head of water being 85 ft. The Torside reservoir, which is the largest of the reservoirs and

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the next in succession, has a capacity of 1,474 million gallons, its area being 160 acres and the maximum depth of water 84 ft. Across the Crowden Brook flowing into this reservoir is constructed one of the separating weirs for separating the pure water from the turbid or flood water by a self-acting process (see Plate 86, 1866); a raised lip with accurately levelled edge is fixed along the top of the weir, and the pure water flowing over this edge with a slow velocity falls direct through a narrow slot beneath into a conduit leading to the storage reservoir or direct to Manchester; but in the case of turbid flood water, the stream having a higher velocity clears the aperture of the slot, and falls down over the outside of the weir, instead of into the pure-water conduit. Lower down Crowden Brook is an embankment where the spring water is separated from the flood water by means of sluices worked by hand, and is turned either into the Torside storage reservoir, or into the Vale House or the Bottoms compensation reservoir, as circumstances may necessitate. At the Rhodes Wood reservoir, which is situated next below the Torside, it has been found necessary to erect a massive masonry abutment at the north end of the embankment, for supporting a land-slip still in progress at that point, and also for conveying the flood water into the new watercourse. From this reservoir the water is conveyed away by a covered conduit for the supply of Manchester, the distance being about 13 miles. The Vale House and Bottoms reservoirs, which are next below the Rhodes Wood, store the compensation water for the supply of millowners having water rights lower down the valley. At the Bottoms reservoir each of the 36 in. discharge valves is worked by a hydraulic cylinder supplied with water under a pressure of about 70 ft.; and immediately below the embankment is the very complete arrangement for discharging the compensation water to millowners, by which the quantity supplied can at any time be tested (see Plates 92 to 94, 1866). The compensation water is discharged at a constant rate through apertures in a gauge plate; and at any time the discharge can be turned into a square measuring basin, whereby the actual quantity discharged during a given interval is ascertained by absolute measurement. At the Arnfield and Hollingworth

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reservoirs, nearer to Manchester, into which the water supply from the Rhodes Wood reservoir is delivered, are two large aerating fountains, each throwing a 9 in. jet to a height of about 40 ft. under pressure from these reservoirs. The Members were invited to luncheon at Tintwistle near the Bottoms reservoir, by the Manchester Local Committee and friends; and returned in the evening by special train to Manchester.

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PROCEEDINGS.

November 1875.

The General Meeting of the Members was held in the Memorial Hall, Albert Square, Manchester, on Friday, 5th November, 1875; John Ramsbottom, Esq., Past-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting in January next.

The following Members were nominated by the Meeting for the election at the Anniversary Meeting:—

PRESIDENT.

Thomas Hawksley,	London.

VICE-PRESIDENTS.

(Six of the number to be elected.)

I. Lowthian Bell, M.P., F.R.S.,	Middlesbrough.
William Clay,	Birkenhead.
Charles Cochrane,	Stourbridge.
Edward A. Cowper,	London.
John Hick, M.P.,	Bolton.
Walter May,	Birmingham.
William Menelaus,	Dowlais.
John Robinson,	Manchester.
Charles P. Stewart,	London.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

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COUNCIL.

(*Five of the number to be elected.*)

Daniel Adamson,	Manchester.
John Anderson, LL.D., F.R.S.E.,	London.
Joseph Armstrong,	Swindon.
Henry Bessemer,	London.
Edgar Gilkes,	Middlesbrough.
Jeremiah Head,	Middlesbrough.
Thomas R. Hetherington,	Manchester.
Henry H. Laird,	Birkenhead.
Joseph Shuttleworth,	Lincoln.
Richard Taylor,	London.
Henry Wren,	Manchester.

The Chairman announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected :—

MEMBERS.

Thomas Adams,	Manchester.
Edward Atkinson,	Whitehaven.
Herbert James Bakewell,	London.
Thomas Beeley,	Manchester.
William Harvey Bisset,	Liverpool.
Charles Candlin,	Mold.
Charles Clayton,	Preston.
Francis Michael Cotton,	London.
Edward Samuel Cowen,	Nottingham.
Richard Curtis,	Manchester.
James Durie,	Manchester.
Thomas Elwell, Jun.,	Paris.
Jean Joseph Leon Farcot,	St. Ouen.
George Ben Goodfellow,	Manchester.
James Kirkwood,	Hong Kong.
Robert Charles Longridge,	Manchester.

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Robert Grant Osborne, ...	Manchester.
William Edmund Rich, ...	London.
George Saxon, ...	Manchester.
John Thompson, ...	Wolverhampton.
George Eastlake Thoms, ...	Liverpool.
James McIntyre Thomson, ...	Glasgow.
William Henry Thwaites, ...	Bradford.
Thomas Unsworth, ...	Manchester.
George Walker, ...	London.
John Scarisbrick Walker, ...	Wigan.

ASSOCIATES.

John Henry Knight, ...	Farnham.
Christopher J. Schofield, . . .	Manchester.
Nanaji Narayan Wasalekar, ...	Manchester.

GRADUATES.

Edward Dawson, ...	Fence Houses.
Francis Henry Deacon, ...	Liverpool.

Mr. A. Paget gave notice to move at the next Anniversary Meeting, with a view to making the Rules accord with the practice of the Institution, that the first article of section V be altered to stand as follows:—"There are to be four General Meetings in each year, three to be held in Birmingham or London, *or elsewhere*, on the fourth Thursday in the months of January, April, and October, *or on such other dates as the Council shall deem more convenient*, and the fourth to be an Annual Meeting held in the summer in different localities to be arranged by the Council; the January Meeting to be the Anniversary Meeting for the annual election of officers."

And that the third article of section III be altered to stand as follows:—"All applications for admission to be communicated by the Secretary to the Council for their approval, previous to being inserted in the ballot list for the election; and the approved ballot

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list to be then forwarded to the Members. The ballot list to specify the name, occupation, and address of the candidates, and also by whom proposed and seconded. The lists to be opened only *in the presence of the Council* on the day of election, by a committee to be appointed for that purpose."

Also to move the following resolutions:—"That this Meeting requests the Council to ask by circular the opinion of each Member of the Institution as to whether it is desirable to move the head-quarters of the Institution to London; and to communicate the result to the Members."

And "That this Meeting requests the Council to ask by circular the opinion of each Member of the Institution as to whether the scientific papers shall be allowed to give reports of the meetings or not; and to communicate the result to the Members."

The following paper was then read:—

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ON MECHANICAL VENTILATORS FOR MINES.

By Mr. WILLIAM DANIEL, of Leeds.

In a paper on Mining Machinery read before this Institution sixteen years ago, by the late Mr. Thomas John Taylor, the Ventilation of Mines by Furnaces placed at the bottom of upcast shafts, as compared with the mechanical appliances then in use, was for valid reasons considered the best and safest method. But, notwithstanding its admitted simplicity, the rarefaction of the outgoing air by heat to produce the ventilating current has proved troublesome, expensive, and dangerous. When the injurious effect of the products of combustion on tubbed shafts is considered, and the enormous consumption of fuel (that for pits of average depth being about 60 lb. of coal per effective H. P. per hour), together with the fact that, where furnaces have to be fired continuously, furnacemen are constantly working at the bottom and additional men are required to be in attendance at the top of the pit in case of accident, some idea may be formed of the expense incurred by the use of the furnace; and a reference to known cases of the ignition of inflammable gases, and of the firing of bituminous shale adjacent to the furnace, both of which so often occur in the coal measures, is sufficient for drawing attention to the danger incurred by furnace ventilation.

Under these circumstances it is not surprising that, since the subject of Mechanical Ventilation was last brought before the Institution at a meeting six years ago, the adoption of the greatly improved mechanical appliances then described for the ventilation of mines should have been so extensive that in this country there are at present about 250 mechanical ventilators in actual use or in course of construction, of which number 180 are the Guibal fans, introduced by M. Guibal, and about 60 are the Waddle fans.

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In the matter of fuel consumption, the best existing appliances will be about on an equality with furnaces when the latter are employed at a depth of about 700 yards; and the less the depth, the greater does the economy of the machine become; but, for the reasons before given, it may certainly be asserted that the furnace ought never to be employed, excepting in small mines where the duration of working and physical conditions are such as not to justify the additional outlay required for a fan.

Most, if not all, of the Mechanical Ventilators at present in use exhaust from the top of the upcast shaft in the case of pits, or at the end of the return air-course where they are employed for day-working; and they may be divided into two classes, namely, those in which a continuous current is maintained by centrifugal action, as in the fans of Guibal, Rammell, Waddle, and others; and those which intermittently discharge a definite quantity, to which class belong the species of rotary pumps introduced by Lemielle and Cooke, the piston machine of Nixon, and the reciprocating air-chambers of Struvé. All these machines excepting Cooke's have been before described in the Institution Proceedings (1856 page 251, 1858 page 63, 1869 pages 78 and 133).

Cooke's Ventilator is shown in Plates 49 to 53. Fig. 1 is a front elevation of the ventilator and engine; and Fig. 2 a back elevation. Fig. 3 is a longitudinal section with the casing open to the drift leading from the mine, showing the admission and discharge, and Fig. 4 a similar section with the mine drift momentarily closed by the rotation of the ventilator drum. Fig. 6 is a plan, with the casings and one drum shown in section and the other drum shown full.

The ventilator consists of a pair of cylindrical casings C C placed side by side, in which revolve eccentric cylindrical drums D D; two swinging shutters S S, suspended at and oscillating about the shaft A, receive motion from the crank B, lever L, and connecting-rod R, so as to be always close to, but not in absolute contact with, the eccentric drum D: the shutter S thus seals the outlet

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while the air is being drawn in from the drift M leading from the mine. The eccentricity of the drums D D is about one-fourth of their diameter; they are about two-thirds the diameter of the casing C, and the width of both casings and drums is about one-half the diameter of the casing. The throw of the crank B is the same as the eccentricity of the drum, the centre of the crank-pin coinciding with the centre line of the drum. The connecting-rod R and lever L are both of the same length as the radius of the casing; and the bottom of the shutter S is curved to a radius of the same length as the crank B or eccentricity of the drums, the curve being a circular arc described from the joint of the connecting-rod R with the lower end of the lever L, as shown in the diagram, Fig. 5, Plate 52. The period of inlet and discharge occupies about 235° of each revolution, and Figs. 1 to 4 show different positions of the drums, the pair of drums being placed opposite each other on the driving shaft G, so that the revolving mass is balanced and the discharge of air equalised.

The drawings show the two ventilators of this construction erected at the Upleatham and Lofthouse Ironstone Mines near Saltburn. The diameter of the casings is 22 ft. and the width of each 11 ft. 6 in.; and the theoretical discharge from the pair of casings in each ventilator is consequently about 4530 cub. ft. per revolution. The ends of the casings are constructed of cast-iron plates bolted together, the circumference being covered by plates of wrought iron, stiffened by rolled H iron joists, Figs. 3 and 4. The drums have cast-iron balanced centres keyed on the cast-iron driving shaft G, with circular flanges, to which are attached the wrought-iron arms placed radially to the drums and riveted at the outer end to T iron rings; on these rings are riveted steel plates forming the circumferences of the drums. The shutters are of wrought iron. The ventilators are driven by semi-portable engines with boilers of the locomotive type, having steam-jacketed cylinders and variable expansion valves.

The useful effect of these machines is measured by the quantity of air discharged, the degree of rarefaction necessary to overcome

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the friction of the passages and ensure the requisite velocity to the ventilating current, and the power expended to produce this effect.

The tabulated statements appended (Table II) contain the results of experiments on some of the different systems previously mentioned that are now working. The quantity of air discharged in each case is that given by the average of a number of anemometer measurements; water-gauge readings were simultaneously taken, and also indicator diagrams from the engines, examples of which are shown in Figs. 7 to 11, Plates 54 and 55. In all cases the observed velocities given by the anemometers were corrected for the friction of the instruments, and the water-gauges were placed on the casings of, or the drifts leading to, the ventilators.

The Leeds fan at Morley Main Colliery in experiments 12 and 13 is a modification of the Guibal fan; the inlets for the air are on both sides, and to prevent interference of the entering currents a diaphragm is placed in the centre of the vanes on the shaft; the shutter is omitted entirely, and the expanding outlet is replaced by a rectangular chimney. The drift leading from the mine to the fan has to be divided for conveying the air to the two sides of the fan; and the driving shaft for the fan requires a third bearing, unless made of excessive strength.

The only two ventilators on Cooke's plan that are at present working have been erected at the Upleatham and Lofthouse Ironstone Mines belonging to Messrs. J. W. Pease and Co., and were adopted by the manager, Mr. Wm. Cockburn, after a careful investigation of the systems in use; and the following experimental results taken from the appended Table II show that his selection was justified, the lowest as well as the highest results being given in the case of the Cooke's ventilators, and the highest alone in the case of the others.

With each ventilator an experiment was made at the ordinary working speed, for which in the case of all the Guibal fans, excepting that at Hilda Colliery, the shutters in the expanding outlets were adjusted, and the best results obtained. The fan at Hilda having been at work only a short time, the proper adjustment of the shutter had not been ascertained.

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		Ventilator. Diam. Width. Ft. Ft.	Air per min. Cub. Ft.	Water Gauge. In.	Revs. per min.	Useful Effect. Per cent.
Cooke	Lofthouse	22 × 11½	101,308	1·12	26	**64·00**
			96,757	1·00	26	**59·16**
„	Upleatham	22 × 11½	88,900	3·25	27	**61·18**
			120,816	1·56	29	**58·50**
Waddle	Aberaman	36 × 1½	126,504	1·60	44	**47·10**
Rammell	Cannock Chase	32 × ½	45,280	2·10	55	**41·02**
Leeds Fan	Morley Main	40 × 10	141,534	1·80	44	**37·92**
Guibal	Farnley Wood	21 × 7	38,900	0·90	53	**50·41**
„	Liverton	36 × 12	121,688	2·55	51	**48·85**
„	Hilda	50 × 12	116,792	2·63	36	**45·81**
„	Skelton	30 × 10	52,544	0·50	28	**45·64**
„	Craggs Hall	30 × 10	56,072	1·40	43	**40·66**

In order to obtain as accurately as possible the volume of air discharged, a great number of anemometer measurements were taken at points equally distributed over the areas of the drifts. In Table I are given the velocities of the air at the respective points in the area of the drifts corresponding to the numbers on the diagrams, Figs. 12 to 18, Plate 56. Attention is particularly required to this, on account of the great variations that occur in different positions in the same air-way. For instance, at Hilda Colliery (experiments Nos. 14 and 15), out of twenty-five observations in each experiment, at the quickest speed the extreme variation was 46 per cent. above the mean and 31 per cent. below; and at the slower speed the velocities varied 38 per cent. and 25 per cent. respectively; so that, if the air had been measured at the points of maximum velocity only, the volume discharged would have been increased from 91,776 to 133,992 cub. ft., and the useful effect from 37·77 to 55·14 per cent. Again, at Lofthouse (experiment No. 6), the variations in nine measurements of the air current were 25 per cent. above the mean and 20 per cent. below; and had the former been assumed in place of the mean velocity, the volume of air would have been increased from 101,308 to 126,635 cub. ft., and the useful effect from 64 to 80 per cent. The drifts shown in the diagrams, Figs. 12 to 18, were divided by cross wires as nearly as possible into squares of equal

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areas, and the anemometer was held in each division for one minute.*

The consumption of fuel in most cases could not be accurately ascertained; for, according to the usual practice, steam was taken from boilers used for other purposes than that of ventilation. But the writer wishes to direct attention to the fact, that, in the majority of ventilators now working, low pressures, very little expansion, and consequently wasteful types of engines, are usually employed, where, owing to the almost constant work, a more economical type of engine might be advantageously adopted. The Lofthouse ventilator, driven by a semi-portable engine as described (indicator diagrams, Fig. 7), during 30 days' continuous working at an average speed of 26 revolutions per minute (obtained from a counter) required $35\frac{1}{8}$ tons of coal, or 3·9 lb. per indicated H. P., or 6·07 lb. per effective H. P. per hour.

Before concluding, the writer wishes to avail himself of this opportunity to thank the proprietors and managers of the different mines at which the experiments were made, for the facilities afforded and assistance rendered to him.

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* In Tables I and II the velocity V of the air in ft. per min. is calculated in each case from the observed number of revolutions R made by the anemometer in one minute, by means of the following formulæ :—

$V = \sqrt{(1{\cdot}03\,R^2 + 83{,}150)}$ for Biram's anemometer in Expts. 1 to 3, and 22 to 26.

$V = \sqrt{(0{\cdot}94\,R^2 + 99{,}210)}$ for Casella's anemometer in Expts. 4 to 16, and 18-19.

$V = \sqrt{(1{\cdot}41\,R^2 + 3{,}283)}$ „ „ „ „ Expt. 17.

By means of a table supplied with the instrument in Expts. 20-21.

TABLE I. *Velocities of Air in different portions of the Area of the Drifts.*

No. of Experiment in Table II.	Upleatham No. 5		Lofthouse No. 8		Cannock Chase No. 9		Aberaman No. 10		Morley Main No. 12		Hilda No. 14		Liverton No. 18	
Position of Anemometer.	Anemometer.	Velocity of Air.	Anemometer.	Velocity of Air.	Anemometer.	Velocity of Air.	Anemometer.	Velocity of Air.	Anemometer.	Velocity of Air.	Anemometer.	Velocity of Air.	Anemometer.	Velocity of Air.
See Plate 56.	Rev.	Ft. p. min.	Rev.	Ft. p. min.	Rev.	Ft. p. min.	Rev.	Ft. p. min.	Rev.	Ft. p. min.	Rev.	Ft. p. min.	Rev.	Ft. p. min.
1	660	713	616	675	1124	1134	579	644	1095	1107	286	420	1261	1262
2	759	800	634	690	1032	1049	620	679	870	900	338	455	1361	1356
3	784	823	538	609	1094	1106	568	634	822	857	392	494	1294	1293
4	757	799	456	543	1170	1177	597	659	973	994	399	499	1337	1333
5	805	842	414	510	1092	1104	593	655	972	994	514	590	1033	1049
6	746	789	646	701	922	948	597	659	1210	1214	572	637	1538	1524
7	751	793	680	731	1162	1170	623	683	1302	1301	491	571	1348	1344
8	963	985	748	791	1204	1209	...	...	...	...	358	469	1489	1477
9	947	971	784	823	1288	1288					301	429	1642	1622
10	834	868	726	771	...	...	...	...	...	...	305	432	1708	1685
11			684	734							331	450	1810	1782
12	...	...	544	614	...	...	...	...	...	...	403	502	1078	1091
13			612	672							546	616	1332	1329
14	...	...	690	739	...	...	...	...	...	...	591	653	1890	1859
15			956	979							662	715	1823	1795
16	...	...	1014	1032	...	...	...	...	...	...	799	836	1736	1712
17			1044	1060							861	892		
18	...	...	914	940	...	...	...	...	...	...	729	774	...	...
19			616	675							635	691		
20	...	...	586	649	...	...	...	...	...	...	662	715	...	...
21											824	859		
22	...	...	...	...	...	...	...	...	...	...	633	690	...	...
23											540	611		
24	...	...	...	...	...	...	...	...	...	...	542	613	...	...
25											741	784		
Mean	800	**837**	695	**744**	1121	**1132**	597	**659**	1035	**1047**	538	**609**	1480	**1469**

Description of Ventilator		Cooke								Rammell	Waddle		Leeds	
Name of Colliery or Mine		Upleatham Iron Mines					Lofthouse Iron Mines			Cannock Chase Colliery	Aberaman Colliery		Morley Main Colliery	
Ventilator, diam. and width	ft.	22×11½					22×11½			32×½	36×1½		40×10	
Date of Experiment	1875	Mar. 6			Aug. 25	Sep. 16	July 21		Oct. 10	June 22	July 13		July 8	
Number of Experiment		1	2	3	4	5	6	7	8	9	10	11	12	13
Anemometer, description		Biram	Biram	Biram	Casella	Casella	Casella	Casella	Casella	Casella	Casella	Casella	Casella	Casella
Do., rev. in 1 min.	rev.	969	850	560	936	800	734	836	695	1121	597	706	1035	1244
Velocity of Air (calculated) V	ft. per min.	1024	909	637	960	837	779	897	744	1132	659	753	1047	1247
Area of Drift . . . . . . A	sq. ft.	125·85	97·75	125·85	125·85	125·85	130·05	130·05	130·05	40·00	168·00	168·00	113·50	113·50
Air per min. . . A×V=C	cub. ft.	128,870	88,900	80,166	120,816	105,422	101,308	116,654	96,757	45,280	110,712	126,504	118,834	141,534
Water Gauge . . . . . W	in.	1·75	3·25	0·75	1·56	1·55	1·125	1·30	1·00	2·10	1·10	1·60	1·30	1·80
Effective H. P. $\frac{C \times W \times 5 \cdot 2}{33{,}000}$ = E	H. P.	35·50	45·50	9·47	29·70	25·75	18·00	23·90	15·24	15·00	19·19	31·89	24·34	40·14
Revs. Engine and Ventilator	per min.	29·30	26·95	19·50	28·78	26·50	26·00	29·92	26·00	55·00	37·00	44·00	36·00	44·00
Cylinders, No., diam., & stroke	in.	2,15,21	2,15,21	2,15,21	2,15,21	2,15,21	2,15,21	2,15,21	2,15,21	1,26,26	1,32,48	1,32,48	1,24,54	1,24,54
Mean effective steam pressure	lb. per in.	53·14	73·57	22·07	47·05	42·65	28·92	34·62	26·125	9·20	5·92	7·88	14·62	19·50
Ind. H. P. from diagrams . I	H. P.	58·59	74·37	16·12	50·75	42·36	28·12	38·74	25·76	36·56	42·69	67·64	64·96	105·80
Effective H. P. . . . . . E	H. P.	35·50	45·50	9·47	29·70	25·75	18·00	23·90	15·24	15·00	19·19	31·89	24·34	40·14
Useful Effect Vent. & Eng. } . . $\frac{E}{I} \times 100$	per cent.	**60·59**	**61·18**	**58·74**	**58·50**	**60·70**	**64·00**	**61·69**	**59·16**	**41·02**	**44·95**	**47·10**	**37·46**	**37·92**

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TABLE II. *Ventilator Experiments (continued.)*

Description of Ventilator		Guibal												
Name of Colliery or Mine		Hilda Colliery				Liverton Iron Mines		Craggs Hall Iron Mines		Skelton Iron Mines		Farnley Wood Colliery		
Ventilator, diam. and width	ft.	50×12				36×12		30×10		30×10		21×7		
Date of Experiment	1875	July 24		Sep. 30		Sep. 17	Oct. 9	Mar. 7		Mar. 8		Mar. 30		
Number of Experiment		14	15	16	17	18	19	20	21	22	23	24	25	26
Anemometer, description		Casella	Casella	Casella	Casella	Casella	Casella	Casella	Casella	Biram	Biram	Biram	Biram	Biram
Do., rev. in 1 min.	rev.	538	348	628	651	1480	1669	94	275	589	272	708	967	327
Velocity of Air (calculated) V	ft. per min.	609	462	685	775	1469	1648	131·6	319·5	665·5	400	774	1022	440
Area of Drift . . . . . . A	sq. ft.	150·70	150·70	150·70	150·70	73·84	73·84	175·50	175·50	131·36	131·36	50·26	50·26	50·26
Air per min. . . . A×V=C	cub. ft.	91,776	69,623	103,229	116,792	108,470	121,688	23,100	56,072	87,157	52,544	38,900	51,366	22,114
Water Gauge . . . . . . W	in.	2·10	0·80	2·40	2·63	2·35	2·55	0·225	1·40	1·50	0·50	0·90	1·65	0·35
Effective H. P. $\frac{C \times W \times 5{\cdot}2}{33{,}000} = E$	H. P.	30·36	8·77	39·00	48·40	40·16	48·89	0·82	12·37	20·60	4·14	5·51	13·35	1·22
Revs. Engine and Ventilator	per min.	32·00	20·00	34·00	36·00	46·93	50·73	14·75	42·75	50·00	28·00	53·33	71·60	32·00
Cylinders, No., diam., & stroke	in.	1,42,42	1,42,42	1,42,42	1,42,42	1,30,30	1,30,30	2,14,16	2,14,16	1,24,24	1,24,24	1,18,18	1,18,18	1,18,18
Mean effective steam pressure	lb. per in.	8·55	3·45	8·95	9·98	16·85	18·42	6·96	28·44	17·08	5·91	8·86	16·13	3·69
Ind. H. P. from diagrams . I	H. P.	80·38	20·27	89·73	105·66	84·69	100·07	2·54	30·42	46·81	9·07	10·93	26·71	2·73
Effective H. P. . . . . . E	H. P.	30·36	8·77	39·00	48·40	40·16	48·89	0·82	12·37	20·60	4·14	5·51	13·35	1·22
Useful Effect Ventr & Eng . . $\frac{E}{I} \times 100$	per cent.	**37·77**	**43·26**	**43·40**	**45·81**	**47·42**	**48·85**	**32·28**	**40·66**	**44·00**	**45·64**	**50·41**	**50·00**	**44·68**

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Mr. DANIEL mentioned that in the ventilator experiments, of which the particulars were given in Table II, the same Biram anemometer had been used in Nos. 1 to 3 and 22 to 26, while in all the rest, except No. 17, the same Casella anemometer had been employed; and if therefore there were any slight difference in the agreement of these two instruments, the quantities of air measured in the several experiments with either anemometer would be relatively correct, but might differ slightly in relation to the experiments made with the other instrument. The same remark applied to No. 17 experiment, at Hilda Colliery, which had been made with another Casella anemometer. When practicable it was of course desirable to take all the measurements with the same instrument.

Mr. E. H. CARBUTT observed that great pains had evidently been taken by the author of the paper in making such a large number of anemometer experiments for measuring the velocity of the air in the mine drifts; and he should have been glad if some information could have been given as to the extent of rubbing surface over which the air currents had had to pass in travelling through the several mines where the measurements had been made, as upon this the amount of friction would greatly depend. In the working of rotary blowers he had found that, in the case of two air passages, having their areas in the proportion of 1 to 4 and their circumferences as 1 to 2, in order to drive equal volumes of air through them in the same space of time, the velocity of the air would require to be fourfold in the smaller passage; and the power expended, from increase of friction &c., would be thirty-two times as great in the smaller as in the larger air passage. The new ventilator now described, acting by displacement of the air, seemed to him a step in the right direction for the ventilation of deep mines, or of old mines with narrow passages. But there were no doubt small and shallow mines which stood in need of mechanical ventilation, but could not afford the cost of such a ventilator as that now described; and for cases of that kind he was now applying a rotary blower acting upon the same principle of displacement, and was obtaining by that

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means a vacuum of 6 in. water gauge, instead of only 3¼ in. which appeared to be the highest that had been realised in the ventilator experiments described in the paper. The principal dimensions of this blower upon Root's system, to give 200,000 cub. ft. of air per minute, were 25 ft. diameter of revolvers and 13 ft. width, the centres of the shafts being 16 ft. apart; and the outlet orifice for the escape of the air was 44 ft. long by 13 ft. wide, allowing the air to escape at slow velocity.

Mr. E. J. C. Welch remarked that—whereas a sliding piece, bearing against the periphery of the eccentric drum, and constrained to travel along a line forming a radius of the circle of revolution of the drum itself, would derive a true harmonic motion from the same—the shutter was stated to be driven by a crank and connecting-rod, by which only an approximate harmonic motion could be obtained; and he enquired therefore how the curve formed at the end of the shutter was determined.

Mr. A. Paget said it would be of interest if some information were given respecting the amount of play or windage between the eccentric drum and the shutter, and between the drum and the casing; some clearance he supposed was left to allow of warping, and the amount would be an important item in calculating the effectiveness of the ventilator.

Mr. E. A. Cowper observed that at first sight the ventilator now described recalled some of the old plans of rotary engines, which had a sliding piston or flap or some other moving contrivance always rubbing against the circumference of the casing or eccentric; but further consideration showed that the present plan was quite admissible, in consequence of there being only a light pressure to deal with, and therefore but slight leakage could occur. As the connecting-rod working the shutter was attached at one end to a crank-pin coinciding exactly with the centre of the drum, while the other end of the rod was the centre from which was struck the circular arc forming the bottom extremity of the shutter, it was

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evident that the sum of the two radii—of the drum and of the shutter—was constantly the same as the length of the connecting-rod; the drum and shutter would therefore work together correctly in all positions, and the amount of clearance between them might be reduced to only the thickness of a sheet of paper by carefully adjusting the connecting-rod to the correct length. With the low pressure of air in working however, the leakage was very insignificant even in the first ventilator erected, in which he understood that, owing to an accidental error in the length of the connecting-rod, the clearance between the shutter and the drum was more than an inch. As there was no rubbing between the circumference of the drum and the casing, and the ends also of the drum he supposed did not rub against the ends of the casing, it was evident that there ought to be very little friction in the working of the machine; and on this account he should have expected to hear of a higher useful effect being obtained. It appeared however that the useful effect was calculated upon the gross Ind. H. P. exerted by the engine, without deducting the friction of the engine itself by taking separate indicator diagrams from the engine when running disconnected from the ventilator. If this were done, he expected the useful effect would be found to compare more favourably with that of the best fans, from which as much as 75 per cent. useful effect was obtained; and he considered so excellent a machine as this ventilator appeared to be ought to do still better than any fan. They were much indebted to the author of the paper for the results of the extensive experiments he had made upon the working of this and other mine ventilators.

Mr. G. F. Deacon enquired which of the anemometers used in the experiments had been found to give the best results. Having himself used different anemometers for measuring the currents of air in sewers, he had found that each instrument failed at low velocities and did not give reasonably accurate results.

Mr. W. S. Hall observed that only one experiment with a Rammell fan was given in the paper, and he did not understand

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why it did not show as high a percentage of duty as the Waddle fan, as it was in fact only a double Waddle fan, with the advantage that it avoided the tendency of the Waddle fan to run endways. It was mentioned that there were 180 Guibal fans now in use, and 60 Waddle fans; and he should be glad to know how many Rammell fans were at work, and to hear some further particulars as to their working.

Mr. A. L. Steavenson said that, having had eighteen years' experience of the use of fans for mine ventilation, he had been much surprised to hear the good results realised with the ventilator now described, particularly as the Guibal fan had hitherto been generally looked upon as unapproachable in useful effect, and deficient only in the degree of vacuum which it was capable of producing. In testing the large Waddle fan at High Park Colliery near Nottingham he had obtained a useful effect of only 40 per cent.; and that construction of fan had seldom yielded better results than those assigned to it in the paper. The low percentage of useful effect obtained with the Guibal fan in these experiments might perhaps be attributable he thought to the special care taken in measuring the velocities of the air, by subdividing the current into so many portions and ascertaining the velocity of each, so as to arrive at a correct average. Excepting the Guibal fan it was evident that there was no fan which could approach the results obtained from the ventilator described in the paper.

The differences observed in the water gauge in the several experiments given in the paper represented the differences in the areas and the rubbing surfaces of the airways through which the air current had to be drawn by the several ventilators. In the ventilator now described the principle of varying capacity was carried out in contradistinction to that of the centrifugal fan. The inferiority of the centrifugal principle was seen in the fact that, if the inlet were closed, a fan would nevertheless be able to continue going round, in consequence of the slip of the air past the blades; but the ventilator now described would either stop under such circumstances or some part of the machinery would have to give

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way. In the Lemielle ventilator, which acted upon the same principle of varying capacities, the re-entry or leakage of air past the blades of the drum was such that at 25 in. water gauge no discharge was obtained. With the Guibal fan nothing above 5 in. water gauge had been reached, and even with the Lemielle ventilator 6 or 7 in. was not exceeded in ordinary working. The principle of varying capacities was the one that he had advocated for many years, and it appeared to be carried out in a very complete manner in the ventilator described in the paper.

Mr. JEREMIAH HEAD enquired whether the casing of the ventilator was turned or trued up inside in any way, or whether any other means were adopted to prevent leakage between the revolving drum and the casing. In Root's blower, acting on a similar principle, a mixture of tallow and black-lead was used, which he understood had a tendency to accumulate and thus make the rubbing surfaces fit truly together even after working for a length of time.

Mr. J. COOKE, as the inventor of the ventilator described in the paper, considered it had not yet by any means yielded the best results of which it was capable, and there was good reason to suppose the effect would be much increased. It had to be noticed that for ventilating a large mine it was wanted to know beforehand what number of revolutions of the engine would be required per minute; and with the Guibal fan and the other fans referred to in the paper it was a great objection to be unable to tell beforehand the result per revolution, and to be in ignorance therefore of the speed at which the engine would have to run, until the fan had been erected and an actual trial made of its capabilities. But this objection was obviated by the principle of varying capacities, because the effect per revolution was known, and consequently also the number of revolutions per minute that the engine would be required to make.

Mr. DANIEL agreed in considering that the water gauge was a sufficient indication of the resistance encountered by the air current

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in the passages of a mine, the height of the gauge increasing as the length of the passages and inversely as their sectional area. All anemometers should be tested in order to obtain a proper formula for correcting the readings, as he had found the tables supplied with the instruments were not to be relied on.

The amount of clearance or play between the revolving drum and the casing of the ventilator was intended to be not more than $\frac{3}{16}$ or $\frac{1}{4}$ inch at most, both at the ends and at the circumference of the casing, and also between the drum and the vibrating shutter; and in the two ventilators now erected this amount of clearance had been adhered to as regarded the ends and the circumference of the casing; but owing to an accidental error of adjustment in keying on the levers working the shutters, the clearance between the curved shutters and the drums was as much as 1 inch or more, instead of only $\frac{1}{4}$ inch. Notwithstanding this extent of clearance however, which continued throughout the whole of the revolution of the drums, it was evident that the amount of leakage must be very inconsiderable, for the actual measured discharge in one of the experiments had amounted to as much as 4166 cub. ft. per rev., and the theoretical maximum displacement amounted to only about 4530 cub. ft. per rev. The flat end-plates of the casings had been planed inside in the two ventilators now at work, so that the drums worked perfectly smooth and true with about $\frac{1}{4}$ inch clearance at each end; but in the ventilators which were now being made it was not intended to plane the end-plates, as they were found to be quite true enough if put together as cast, without planing; the end-plates were now being cast in rather larger segments than in the two first ventilators. In making the drums, the T iron rings were turned perfectly circular, and then covered with the sheeting of steel plates 1-16th inch thick. The circumference of the casing being similarly constructed, the whole of the ventilator was thus made of iron or steel, and could be erected very quickly; very slight foundations were required, consisting only of the two low parallel walls for carrying the cross girders on which the ventilator casing was fixed. The cost of the Upleatham and Lofthouse ventilators, including in each case the pair of drums and casings with engine and boiler complete, had

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been about £4500 each; whilst to do the same work as either of these ventilators the cost of a Guibal fan, including the brickwork, would be from £7000 to £8000.

In the experiments with the ventilators he regretted there had not been the means of disconnecting the engine and running it separately from the ventilator; and it had therefore been impossible to obtain indicator diagrams showing the friction of the engine alone. It would also have been desirable to obtain diagrams showing the power required to drive the ventilator when running without any water-gauge pressure, so as to ascertain the friction of the machine as well as of the engine; but that could only have been done by opening the air drifts close to the ventilator, which was impracticable on account of stopping the mine ventilation.

The number of Rammell fans now in use he believed was not more than six or seven; he had not been able to obtain an opportunity of experimenting upon any others than the one at the Cannock Chase Colliery.

The CHAIRMAN considered the ventilator described in the paper possessed a decided advantage over a fan in the circumstance that, like the Root's blower, it discharged a definite volume of air at each revolution, and the effect due to each revolution was thus known beforehand. As regarded leakage, whether between the drum and the shutter or the drum and the casing, he suggested that the amount might be easily ascertained by blocking up either the inlet from the mine or the discharge from the ventilator, and then putting the machine in motion and observing the speed at which the leakage would admit of its being driven under those conditions, and noting the corresponding water gauge that was obtained; this would give a true measure of the whole amount of leakage. In any case a much higher result in useful effect would be secured by this ventilator than could be obtained from any fan yet introduced. It was unfortunate that there had not been the means of ascertaining the resistance of the engines driving the ventilators, in order that the power expended in useful work might be correctly known; but they were much indebted to the author of the paper for the great pains

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he had taken in carrying out so extensive a series of experiments upon different kinds of ventilators.

He proposed a vote of thanks to Mr. Daniel for his paper, which was passed.

The following paper was then read :—

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ON THE ULTIMATE CAPACITY OF BLAST FURNACES.

BY MR. CHARLES COCHRANE, OF STOURBRIDGE.

In a paper read before this Institution in 1869, "On the Further Utilisation of the Waste Gas from Blast Furnaces, and the Economy of Coke due to Increased Capacity of Furnace," the writer ventured upon the prediction that by increased capacity of furnace from 20,624 to 47,528 cub. ft. the consumption of coke might be reduced to 17·9 cwt. per ton of No. 4 iron made in the Cleveland district, under the conditions of quality of materials and temperature of blast described at the time; and it was expected that this saving would result solely from the further absorption of sensible heat from the gases then escaping at the tunnel head at a temperature of 560° Fahr., the calcined ironstone containing about 40 per cent. of iron, and the blast being supplied at a temperature of 1000°. In a subsequent paper read in 1870, the writer (profiting by the valuable aid rendered by Mr. Bell in first attempting to lay down a curve which should at once embody at a glance known facts as to effects of capacity of furnace) further ventured to reduce his experience of large-sized furnaces and high temperatures of blast to general conclusions in the shape of definite curves: the one, Fig. 5, Plate 58, showing the saving due to heat of blast in a furnace of 20,624 cub. ft. capacity; the other, Fig. 8, Plate 59, showing the further saving due to capacity of furnace. To these curves constant reference will be made in this paper, as the writer believes that they are still (as then he believed them to be) practically true, and that every divergence from them can be satisfactorily accounted for in the facts about to be presented. The economy predicted in 1869 was a speculation which has failed to be verified; but the curves, within the limit of 33,000 cub. ft. capacity, have been proved by experience to be reliable.

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Since that time the writer has had the experience of two furnaces of very large capacity, one of them, No. 1, being of the section shown in the diagram, Fig. 2, Plate 57, 90 ft. high by 29 ft. bosh, and possessing a capacity of 33,140 cub. ft.; the other, No. 2, being 90 ft. by 30 ft., as shown in Fig. 4, and possessing a capacity of 40,500 cub. ft. As regards the latter furnace, owing to insufficient power of blast and irregularity of supply of materials, no definite confirmation of anticipated results was obtained. The pressure of blast rarely reached 3 lb. per sq. in., and for many months of the period did not exceed $2\frac{1}{2}$ lb., a pressure which was inadequate to prevent the frequent and almost constant formation of scaffolds at all the furnaces, ending at length in the complete stoppage of the one of largest capacity, after having only been at work for a period of two years; and the narrow escape of two other furnaces, Nos. 3 and 4, each of 20,624 cub. ft. capacity (Fig. 1), from sharing a similar fate.

It may be interesting to compare the working of the furnaces of different capacities over the years 1871 and 1872, in order to show how, in all alike, similar dissappointment arose, and how, under similar conditions, the economy due to increased capacity failed to assert itself. The reason for this the writer hopes to show in the present paper. In the diagram, Fig. 6, Plate 58, are shown the details of the working of No. 2 furnace of large capacity (40,500 cub. ft.) over the year 1871. In nine months ending December 1871 there were consumed at this furnace 22·75 cwt. of coke per ton of No. 4·18 iron, the temperature of blast being 1142°, and that of the escaping gases 505° + say 100° = 605°. In nine months ending December 1871 there were consumed at No. 3 furnace, of 20,624 cub. ft. capacity, 23·22 cwt. of coke per ton of 3·74 iron made, the temperature of blast being 1355°, and that of the escaping gases being 598° + 140° = 738°. In the former case the consumption should have been, according to calculation, only 20·50 cwt., whilst in the latter it should have been only 20·40 cwt., according to the data given in the paper of 1870. In nine months ending December 1871 there were consumed at No. 4 furnace, also of 20,624 cub. ft.

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capacity, 23·51 cwt. of coke per ton of 4·08 average quality of iron made, the temperature of blast being 1328°, and that of the escaping gases being 583° + 140° = 723°. In this case the consumption of coke should have been only 20·55 cwt., according to previous experience of similar temperature at the same furnace. The average working of Nos. 3 and 4 furnaces, during the nine months of 1871 referred to, was

Coke consumption $\frac{23{\cdot}22+23{\cdot}51}{2}=23{\cdot}36$ cwt. per ton of $\frac{3{\cdot}74+4{\cdot}08}{2}=3{\cdot}91$ iron

Temperature of blast . . . . $\frac{1355+1328}{2}=1341°$

Temperature of escaping gases . . . . $\frac{738+723}{2}=730°$

For the moment, these results would seem to point to the conclusion that temperature of blast, and capacity of furnace after a certain dimension was reached, would be simply replaceable items in the working of a blast furnace; for notwithstanding a reduction in temperature of blast of 199°, the consumption of coke was 22·75 cwt. in the larger against 23·36 cwt. as the average of the two smaller furnaces, of nearly 20,000 cub. ft. less capacity. It will hereafter be shown however that the heavy scaffolds, to which the large furnace was constantly subjected, reduced in effect its working capacity to one of about 18,000 cub. ft., whilst Nos. 3 and 4 furnaces worked no better than furnaces of 10,000 cub. ft. capacity should do.

Somewhat better results attended the working of the large furnace of 40,500 cub. ft. capacity during the year 1872, but the average of the year's working still fell considerably short of what was expected. In eleven months ending November 1872 there were consumed 21·41 cwt. of coke per ton of 4·31 iron, the temperature of blast being 1195°, and that of the escaping gases 368° + 60° = 428°. Diagram Fig. 7, Plate 58, shows the details of the working of this furnace over the eleven months of 1872. By way of comparison, it may here be stated that at the smaller furnace, No. 3, during the twelve months of the year there were consumed 24·20 cwt. of coke per ton of 4·00 average quality of iron made, the average temperature of blast being 1133°, and that of the escaping gases 546° + 140° = 686°. No. 4 furnace, also of 20,624 cub. ft.

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capacity, during the same period consumed 24·36 cwt. of coke per ton of No. 3·99 iron, the average temperature of blast being 1143°, and that of the escaping gases 544° + 140° = 684°.

The estimated average for the largest furnace, working at 1195°, should have been only 19·50 cwt. according to expectation: thus showing an excess in consumption of 1·91 cwt. per ton of iron, and reducing the effective capacity of the furnace to one of 21,000 cub. ft., according to the heat and capacity curves. In a similar way, Nos. 3 and 4 furnaces should have worked with only 22·20 cwt. and 22·00 cwt., at the temperature of 1133° and 1143° respectively: showing an excess in consumption of 2·00 cwt. at the former and 2·36 cwt. at the latter, the effective capacities of the furnaces in these cases being respectively 13,000 and 12,500 cub. ft. The best result attained during 1872 at No. 2 furnace was in the month of April, when, with blast at a temperature of 1385°, the consumption of coke fell to 18·93 cwt. per ton of iron of an average quality of 3·59; the recorded temperature of the escaping gases over the month being 456°, when the effective capacity of the furnace rose to 31,000 cub. ft.

During 1873 there was no opportunity of contrasting the working of a large furnace of such capacity as that of No. 2 with the two others, each of 20,624 cub. ft. capacity; but the result of the year's working showed at the furnaces of lesser capacity a uniformity which may be worth while to record. No. 3 furnace worked with an average temperature of blast of 1238°, and consumed 23·10 cwt. of coke per ton of iron made of 3·78 quality; whilst No. 4, of equal capacity, worked with an average temperature of 1254°, and consumed 23·20 cwt. of coke per ton of iron made of 3·86 quality: the temperature of the escaping gases at No. 3 furnace being 548° + 140° = 688°, and at No. 4 furnace 596° + 140° = 736°. The coke averaged throughout the year 0·67 per cent. water, 7·31 per cent. ash, with sulphur 1·01 per cent., making a total of 8·99 per cent. of foreign matter; the ironstone contained about 40 per cent. of iron.

In March 1874 No. 1 furnace of 33,140 cub. ft. capacity, shown in Fig. 2, Plate 57, was blown in, and worked with an average

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temperature of blast of about 1238° over a period of eight months, consuming 21·17 cwt. of coke per ton of iron made of 3·63 quality: the temperature of the escaping gases being 329° + 60° = 389°. The estimated consumption of coke should have been only 19·60 cwt., showing an excess in consumption of 1·57 cwt. No. 3 furnace, over ten months of the year 1874, worked with an average temperature of blast of 1315°, and consumed 23·64 cwt. of coke to produce 3·57 quality of iron, instead of 20·66 cwt. at which it ought to have worked according to previous experience: the temperature of the escaping gases being 572°+140°=712°. No. 4 furnace of 20,624 cub. ft., over the same ten months, worked with an average temperature of blast of 1261°, and consumed 23·92 cwt. of coke per ton of iron of 3·66 average quality, the temperature of the escaping gases being 584°+140°=724°. This is 3·02 cwt. per ton in excess of previous working of the furnace at the same temperature for a slightly higher number of quality of iron. The coke during the year averaged 0·63 per cent. water, 7·98 per cent. ash, and 0·80 per cent. sulphur, making a total of 9·41 per cent. of foreign matter.

The full particulars of the working of the furnaces during five successive years are given in the following Table:—

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Average Working of Blast Furnaces at Ormesby Iron Works, Middlesbrough.

Year.	Furnace. No.	Furnace. Capacity.	Time of working.	Temperature. Blast.	Temperature. Escaping Gases.	Coke per ton of Iron made. Actual Consumption.	Coke per ton of Iron made. Estimated from previous experience.	Coke per ton of Iron made. Excess of Consumption.	Iron made. Quality.	Iron made. Quantity per month.	Blast Pressure at plug-hole. Lbs. per sq. in.	Impurities in the Coke.
		Cub. Ft.	Months.	Fahr.	Fahr.	Cwt.	Cwt.	Cwt.	No.	Tons.	Lbs.	Per cent.
1871	2	40,500	9	1142	605*	22·75	20·50	2·25	4·18	1752	2·54	Water 0·87
	3	20,624	9	1355	738	23·22	20·40	2·82	3·74	1739	2·59	Ash 5·77
	4	20,624	11	1308	719	23·53	20·66	2·87	4·06	1777	2·55	Sulph. 0·82
												—7·46
1872	2	40,500	11	1195	428	21·41	19·50	1·91	4·31	1324	2·92	Water 1·81
	3	20,624	12	1133	686	24·20	22·20	2·00	4·00	1513	2·73	Ash 5·93
	4	20,624	12	1143	684	24·36	22·00	2·36	3·99	1572	2·75	Sulph. 0·75
												—8·49
1873	2	40,500	not working	—	—	—	—	—	—	—	—	Water 0·67
	3	20,624	12	1238	688	23·10	21·25	1·85	3·78	1720	3·50	Ash 7·31
	4	20,624	12	1254	736	23·20	21·10	2·10	3·86	1784	3·48	Sulph. 1·01
												—8·99
1874	1	33,140	8	1238	389	21·17†	19·60	1·57	3·63	1486	4·04	Water 0·63
	3	20,624	10	1315	712	23·64	20·66	2·98	3·57	1512	4·04	Ash 7·98
	4	20,624	10	1261	724	23·92	20·90	3·02	3·66	1627	4·04	Sulph. 0·80
												—9·41
1875	1	33,140	8	1210	374	20·69	19·75	0·94	3·34	1662	3·72	Water 0·46
	3	20,624	8	1258	681	24·14	21·00	3·14	3·24	1675	3·70	Ash 7·61
	4	20,624	8	1251	688	24·38	21·00	3·38	3·49	1702	3·72	Sulph. 0·92
												—8·99

* About. † A furnace of 20,624 cub. ft. capacity also worked with this consumption of coke at the same temperature of blast.

From this table it will be seen that over the entire period of four years, 1871 to 1874, there has been an excess in consumption of coke at all the furnaces, ranging from 1·57 to 3·02 cwt. per ton of iron: in the cases of Nos. 3 and 4 furnaces the excess is above the *actual* results obtained at like temperatures of blast as indicated in the paper of 1870; whilst at No. 2 furnace of 40,500 cub. ft. capacity the excess is above the *estimated* consumption based on calculation and shown by the capacity curves. That some common causes have operated to produce such excess at all the furnaces must be admitted, though it may be difficult to point out the precise cause or causes which have been in operation. The writer's impression is that the excess in consumption corresponds with a practical reduction in the effective working capacity of the furnaces, evidenced in the increased temperature of the escaping gases: the reduction in effective capacity being partly due to scaffoldings arising out of circumstances of inferior pressure of blast, or irregularity and inferiority of materials employed, specially as relates to their mechanical condition,—and partly, as shown afterwards, to the escape of gas through the sides of the furnaces. Taking the average working of Nos. 3 and 4 furnaces over the four years 1871 to 1874, the results are as follows:—

		Temperature.		Consumption of Coke.			Average
		Blast.	Escaping Gases.	Actual. Cwt.	Estimated. Cwt.	Excess. Cwt.	quality of Iron.
1871	No. 3	1355°	738°	23·22	20·40	2·82	3·74
	No. 4	1308°	719°	23·53	20·66	2·87	4·06
1872	No. 3	1133°	686°	24·20	22·20	2·00	4·00
	No. 4	1143°	684°	24·36	22·00	2·36	3·99
1873	No. 3	1238°	688°	23·10	21·25	1·85	3·78
	No. 4	1254°	736°	23·20	21·10	2·10	3·86
1874	No. 3	1315°	712°	23·64	20·66	2·98	3·57
	No. 4	1261°	724°	23·92	20·90	3·02	3·66
	Average	1251°	711°	23·65	21·15	2·50	3·83

It was recorded in the former paper of 1870 (page 73) that the consumption of coke for No. 3·82 iron was 20·10 cwt., the temperature of blast being 1422°, whilst that of the escaping gases was 560°. On reference to the curve shown in Fig. 5, Plate 58,

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which accompanied the same paper, it is seen that at 1251° the consumption of coke should be about 21·10 cwt., which agrees as nearly as may be with the estimated average above shown of 21·15 cwt.; so that there has been 2½ cwt. of coke consumed in excess of what should have been, and this extra consumption has been accompanied with a rise in temperature of the escaping gases from 560° to 711°, or 151° rise. In the one case the weight of gases escaping at the tunnel head corresponds with a consumption of 23·65 cwt. at 711°, and in the other with a consumption of 21·15 cwt. at 560°. According to Mr. Bell's estimate,* the weight of the escaping gases will be found as follows, for a consumption of 21·15 cwt. of coke and 11·00 cwt. of limestone per ton of iron made, each ton of pig being assumed to contain only 18·60 cwt. of pure iron :—

	cwt.		
Coke consumption per ton of iron made .	21·15		
Less ash &c., 8·59 per cent.	1·81		
Carbon in Coke	19·34		
Carbon in Limestone, 12 per cent. of 11·00 cwt.	1·32		
Total carbon per ton of iron made . .	20·66		
Less, carbon in pig, say 3 per cent. . .	0·60		
Carbon in escaping gases	20·06		
Carbon in carbonic acid from reduction of ore, $\frac{9}{28} \times 18·60$ cwt.	5·98		
Carbon deposition	0·60		
	6·58 = carb. acid		24·13
Leaving carbon as carbonic oxide . .	13·48 = carb. oxide		31·45
	20·06		55·58
		cwt.	
Carbon in gases	20·06	55·58	
Oxygen in gases, 55·58 less 20·06 cwt. .	35·52		
Oxygen from ore and carbonic acid . .	12·45		
Difference, oxygen from blast considered dry	23·07		
Nitrogen with this oxygen, 23·07 cwt. × 3·33	76·82	76·82	
Weight of dry blast	99·89		
Total Weight of dry gases per ton of iron made .		132·40 cwt.	

* Chemical Phenomena of Iron Smelting, page 186.

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For another mode of arriving at the weight of escaping gases with a consumption of 21·15 cwt., reference may be made to Gordon's translation of Grüner's work on Blast-Furnace Phenomena; and assuming the analysis of the gases to be the same as given there (page 46), though this is liable to a slight error, the calculation gives 126 cwt. per ton of iron as the weight of the moist gases escaping.*

Adopting in the following calculations the estimate of Mr. Bell, it is seen that at 560°, with the consumption of 21·15 cwt. of coke per ton of iron, the weight of escaping gases, after correction for impurities in the coke, would be 132·4 cwt. per ton of iron made. The weight of gases escaping in the case of 23·65 cwt. of coke consumed per ton of iron would be approximately $\frac{23\cdot65}{21\cdot15} \times 132\cdot4 = 148\cdot0$ cwt. It follows that 15·6 cwt. more gas has escaped from the same furnaces than formerly, and at a temperature higher by $711° - 560° = 151°$. Thus in the worse case 15·6 cwt.=1,747 lb. heated to 711° escapes in excess; whilst in addition 132·4 cwt.=14,828 lb. escapes at 151° higher temperature than the equal volume passing off from the furnaces formerly under more favourable conditions. The difference will therefore stand as follows when expressed in heat-units:—

1,747 × 711 × 0·275 (specific heat)		= 341,582	heat-units
14,828 × 151 × 0·275	„	= 615,732	„ „
Total		957,314	„ „

Taking 4,000 heat-units to represent 1 lb. of carbon burnt into carbonic oxide, the above 957,314 units represent 239 lb. of carbon, equal to 261 lb. or 2·33 cwt. of coke wasted, which fairly explains the difference of 2·50 cwt. indicated in actual practice. The writer can hardly think that greater accuracy could be expected in proof that the theory of absorption of sensible heat holds good in furnaces of such a capacity as that referred to, namely 20,624 cub. ft. The increased temperature of the escaping gases corresponds, in his opinion, to a practical reduction of the capacity of the furnace from 20,624 cub. ft. to something between 10,000 and 11,000 cub. ft.,

* See Appendix.

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as indicated by the capacity curves in Fig. 8, Plate 59; and he concludes that, as soon as the effective capacity can be increased to the full size of the furnace, the former excellent working will be restored, and the 2·50 cwt. consumed over the period referred to in excess of what should have been consumed will be got rid of.

Applying these considerations to the larger furnace of 40,500 cub. ft. capacity, in 1871 the temperature of the blast was 1142°, and that of the escaping gases 605°. This high degree of temperature of the escaping gases, exceeding that of 560° at which furnaces of about half the size were wont to work, was notoriously due to irregular supply of materials, inferiority of quality, and low pressure of blast, occasioning scaffoldings of a most formidable character, and making the successful trial of the furnace on its merits a sheer impossibility. Even here however it cannot fail to be noticed that, despite the disadvantages of the trial, the extra capacity more than compensated for the inferior temperature of blast, by which, according to the heat curve in Fig. 5, Plate 58, 1·25 cwt. of coke was sacrificed. At Nos. 3 and 4 furnaces the average temperature of blast was 1331°, that of the escaping gases was 728°, and the average consumption of coke was 23·37 cwt.; whilst at No. 2 furnace the average temperature of blast was 1142°, that of the escaping gases 605°, and the actual consumption of coke 22·75 cwt., thus proving itself better by 0·62 cwt. of coke, though working at 189° lower temperature of blast. The total difference in favour of No. 2 furnace is therefore 1·87 cwt.; but nevertheless the results show that the large furnace, although of 40,500 cub. ft. capacity, was only working as one of 17,000 to 18,000 cub. ft. capacity, according to the capacity curves, Fig. 8, Plate 59; whilst Nos. 3 and 4 worked no better than furnaces of about 11,000 cub. ft. should have done.

It has now to be seen how far this explanation will bear the test of investigation at the tunnel head, where in the case of Nos. 3 and 4 the average temperature is 728°, and at No. 2 about 605°. The weight of gases escaping in the former case, due to the consumption of 23·37 cwt. of coke per ton of iron, will be found to be about

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$132{\cdot}4 \times \frac{23{\cdot}37}{21{\cdot}15} = 146{\cdot}3$ cwt. The weight of gases escaping in the latter case, due to the consumption of 22·75 cwt., will be found to be about $132{\cdot}4 \times \frac{22{\cdot}75}{21{\cdot}15} = 142{\cdot}4$ cwt. It follows that 3·9 cwt. more gas has escaped at the smaller furnaces than at the larger, and at a temperature higher by 123°. Hence 3·9 cwt.$=$436 lb. heated to 728° escapes in excess in the case of the smaller furnaces; whilst in addition 142·4 cwt.$=$15,949 lb. escapes at 123° higher temperature. The difference expressed in heat-units stands therefore as follows:—

436 × 728 × 0·275 (specific heat)	= 87,287	heat-units
15,949 × 123 × 0·275 „	= 539,474	„ „
Total	626,761	„ „

At 4000 heat-units per lb. of carbon burnt into carbonic oxide, the above represents an absorption of 157 lb. of carbon in the escaping gases. Adding for 7·46 per cent. of impurities in the coke, this represents an extra consumption of 169 lb.$=$1·51 cwt. of coke in the smaller furnaces; and the extra consumption due to loss of temperature of blast at the larger furnace being 1·25 cwt. according to the heat curve in Fig. 5, the calculated excess of consumption in the smaller furnaces is thus 0·26 cwt. as compared with 0·62 cwt. actual excess.

Passing on to 1872, in which year the results obtained at the larger furnace of 40,500 cub. ft. capacity were better than those in 1871 though still falling short of what was expected, it is found that this furnace worked with an average temperature of blast of 1195°, the temperature of the escaping gases having fallen to 428°. During the same year Nos. 3 and 4 furnaces worked with an average temperature of blast of 1138°, whilst that of the escaping gases averaged 685°. The average consumption of coke was 24·28 cwt. per ton at Nos. 3 and 4 furnaces, whilst that at No. 2 was 21·41 cwt., thus showing itself better by 2·87 cwt. per ton of iron made, working however at 57° higher temperature of blast: so that in this case both higher temperature of blast and larger effective capacity of furnace have to be taken into consideration. For higher temperature of blast, on reference to the temperature curve, Fig. 5, for a furnace of 20,624

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cub. ft. capacity, it is found that 57° higher temperature at Nos. 3 and 4 furnaces would have enabled those furnaces to work at about 23·62 cwt. instead of 24·28 cwt. per ton of iron made, leaving 2·21 cwt. of saving to be accounted for by extra effective capacity. How does this accord with the actual facts recorded in the diminished temperature of the escaping gases, namely 428° at No. 2 furnace against 685° at the smaller? The weight of gases passing off at the smaller furnaces of 20,624 cub. ft. capacity may be estimated at $132{\cdot}4 \times \frac{24{\cdot}28}{21{\cdot}15} = 152{\cdot}0$ cwt. The weight of gases escaping in the case of the larger furnace of 40,500 cub. ft. capacity may be taken at $132{\cdot}4 \times \frac{21{\cdot}41}{21{\cdot}15} = 134{\cdot}0$ cwt. It follows that 18·0 cwt. more gas per ton of iron has escaped at the smaller furnaces than at the larger, and at a temperature higher by $685° - 428° = 257°$; so that 18·0 cwt. = 2016 lb. heated to 685° escapes in excess at the smaller furnaces, whilst in addition 134·0 cwt. = 15,008 lb. escapes at 257° higher temperature. The difference in heat-units stands therefore as follows:—

2,016 × 685 × 0·275 (specific heat)	=	379,764	heat-units
15,008 × 257 × 0·275 „	=	1,060,690	„ „
Total		1,440,454	„ „

At 4000 units per lb. of carbon burnt into carbonic oxide, the above units represent an absorption of 360 lb. of carbon, equal (after making an allowance corresponding to 8·49 per cent. of impurities) to 393 lb. or 3·51 cwt. of coke, which more than accounts for the 2·21 cwt. saving due to extra capacity of furnace. Such a reduced temperature of the escaping gases at No. 2 furnace is, the writer feels assured, mainly due to the large escape of gas which took place at that furnace through the cracks and fissures in the brickwork, owing to the crinoline arrangement of hoops being defective in construction, and so allowing the brickwork to expand and crack. The result would obviously be that less gas would reach the tunnel head, and the gas would be lowered more in temperature by contact with the incoming materials than if all had travelled to the same point; whilst gas which failed to reach the tunnel head would escape at a higher temperature, the lower the point of escape.

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In the above cases it is found by means of the capacity curves in Fig. 8 that No. 2 furnace worked as a furnace of only 22,500 cub. ft. capacity, whilst Nos. 3 and 4 furnaces worked as if only of 12,700 cub. ft. capacity. It will be noticed that the make at No. 2, the largest furnace, was only 1324 tons per month, whilst 1542 tons per month was the average of the two smaller. The temperatures of the escaping gases, it should be mentioned, were recorded at the base of the descending main, and it is possible that a correction of 80°, which has been made to arrive at the probable temperature at the top of the large furnace, is insufficient in the case of the year 1872, owing to the smallness of the make, and the probability that the loss by radiation in descending through a tube 90 ft. long was greater. In fact, on making a comparison between No. 2 furnace working in 1871 and in 1872, it will be seen that in 1871, 22·75 cwt. of coke was consumed, whilst in 1872 at the same furnace 21·41 cwt. of coke was consumed, the difference being 1·34 cwt. in favour of 1872. The average temperature of blast in 1872 was 1195°, against 1142° in 1871, equivalent to a saving of about 0·25 cwt. out of the 1·34 cwt., according to the temperature curve in Fig. 5, and leaving only 1·09 cwt. per ton of iron to be accounted for by reduced temperature of the escaping gases, equal to say 1·01 cwt. of pure carbon.

$$1{\cdot}01 \text{ cwt.} \times 112 \text{ lb.} \times 4000 \text{ heat-units} = 452{,}480 \text{ heat-units.}$$

The weight of gas escaping in 1871 at 605° from No. 2 furnace may be taken at

$$132{\cdot}4 \times \frac{22{\cdot}75}{21{\cdot}15} = 142{\cdot}4 \text{ cwt.}$$

and the gas escaping in 1872 at 428° may be taken at

$$132{\cdot}4 \times \frac{21{\cdot}41}{21{\cdot}15} = 134{\cdot}0 \text{ cwt.}$$

$$\text{Difference} \quad 8{\cdot}4 \text{ cwt.}$$

Hence 8·4 cwt. = 940 lb. more gas per ton of iron should have escaped at the higher temperature in 1871, whilst in addition 134·0 cwt. = 15,008 lb. should have escaped at the difference of temperature.

940 × 605° × 0·275 (specific heat)	=	156,392	heat-units
15,008 × x × 0·275 „	=	296,088	„ „
Total (same as above) .		452,480	„ „

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from which x (the calculated difference of temperature) = 71°, whereas the recorded difference of temperature is 605° − 428° = 177°. The substantial fact therefore remains that the diminution of temperature in the escaping gases is more than sufficient to explain the recorded saving of coke.

It may be interesting to note that in ascertaining the increase to be made in the temperature of the escaping gases as recorded at the base of the descending mains, in order to arrive at the temperature at the top of the furnaces, the curious but perhaps obvious circumstance was disclosed, that the gases in descending the length of 90 ft. of main at the large furnace lost only 60° in temperature, whilst the loss in descending 76 ft. at the smaller furnaces was as much as 140°. In the former case the temperature fell from 290° to 230°, and in the latter from 760° to 620°. The smaller fall in temperature is of course due to the lower temperature of the escaping gases at the higher furnace, so that notwithstanding the extra travel of 14 ft., the loss by radiation to the external atmosphere is less.

In 1873—during which no large furnace was at work, the difficulties of 1871 and 1872 having finally culminated in the blowing out of the large furnace—it is found that Nos. 3 and 4 furnaces, each of 20,624 cub. ft. capacity, worked with an average temperature of blast of 1246°; of escaping gases of 712°; average consumption of coke 23·15 cwt., where it should have been only $\frac{21{\cdot}25 + 21{\cdot}10}{2} = 21{\cdot}18$ cwt., showing an excess in consumption of 1·97 cwt. over what the furnace should have consumed, had the gases escaped as formerly at 560°. Here is a difference of 152° alone to account for the extra consumption of coke, if the writer's surmise be correct; and it will now be seen whether this 152° will explain the difference. The weight of gases actually escaping in 1873 per ton of iron made will have been approximately

$$132{\cdot}4 \times \frac{23{\cdot}15}{21{\cdot}15} = 144{\cdot}9 \text{ cwt.}$$

whereas it should have been only

$$132{\cdot}4 \times \frac{21{\cdot}18}{21{\cdot}15} = 132{\cdot}5 \text{ cwt.}$$

Difference . . . 12·4 cwt.

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Hence 12·4 cwt. = 1388 lb. of gas escapes in 1873 more than should have escaped, and at the higher temperature of 712°; whilst in addition 132·5 cwt. = 14,840 lb. escapes at an extra temperature of 152°.

1,388 × 712° × 0·275 (specific heat)	=	271,770	heat-units
14,840 × 152° × 0·275	„	= 620,312	„ „
Total		892,082	„ „

At 4000 units per lb. of carbon burnt into carbonic oxide the above units represent an absorption of 223 lb. of carbon, which, corrected for 8·99 per cent. of impurities, is equivalent to a waste of 245 lb. of coke, against 1·97 cwt. = 221 lb. actual difference to be explained. This is a very close agreement, and on reference to the capacity curves in Fig. 8 it will be seen that the average working of the furnaces over 1873 was that of a furnace of 12,500 cub. ft. capacity.

Passing now to 1874, No. 1 furnace of 33,140 cub. ft. capacity is found working with an average temperature of 1238°, that of the escaping gases being 389°; whilst Nos. 3 and 4 furnaces, each of 20,624 cub. ft. capacity, worked with an average of 1288° temperature of blast, that of the escaping gases being 718°. The coke consumption averaged in the former case 21·17 cwt., in the latter 23·78 cwt., indicating a saving of 2·61 cwt. per ton of iron made at the larger furnace, with 50° lower temperature of blast, and 329° lower temperature of the escaping gases. Had Nos. 3 and 4 furnaces worked with only 1238° of blast, the consumption of coke would have been about 0·33 cwt. more, say 24·11 cwt., showing a real saving of 2·94 cwt. of coke to be accounted for by reason of extra effective capacity of the larger over the smaller furnace.

How does this accord with the actual facts recorded in the diminished temperature of the escaping gases, 389° at the larger furnace, against 718° at the smaller? The weight of gases passing off at the smaller furnaces of 20,624 cub. ft. capacity may be estimated at

$$132{\cdot}4 \times \frac{23{\cdot}78}{21{\cdot}15} = 148{\cdot}8 \text{ cwt.}$$

The weight of gases escaping in the larger furnace of 33,140 cub. ft. capacity may be taken at

$$132{\cdot}4 \times \frac{21{\cdot}17}{21{\cdot}15} = 132{\cdot}5 \text{ cwt.}$$

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It follows that 148·8−132·5=16·3 cwt. more gas has escaped at the smaller furnace than at the larger, and at a temperature higher by 329°. Hence 16·3 cwt.=1825 lb. heated to 718° escapes in excess at the smaller furnace, whilst in addition 132·5 cwt.=14,840 lb. escapes at the smaller furnace at 329° higher temperature.

1,825 × 718 × 0·275 (specific heat)	= 360,346	heat-units
14,840 × 329 × 0·275 "	=1,342,649	" "
Total	1,702,995	" "

At 4000 units per lb. of carbon burnt into carbonic oxide, the above units represent an absorption of 425 lb., equivalent (after correction for 9·41 per cent. of ash) to 469 lb. of coke, which more than accounts on the writer's supposition for the actual saving recorded over the year of 2·94 cwt.=329 lb. of coke.

It will be further seen, on reference to the capacity curves in Fig. 8, that No. 1 furnace of 33,140 cub. ft. capacity worked as one of 21,000 cub. ft., whilst Nos. 3 and 4 furnaces of 20,624 cub. ft. capacity each worked as one of only 10,500 cub. ft., showing how badly they worked during the year, whilst No. 1 approached within 1·57 cwt. of the calculated amount for its capacity of furnace. The writer thinks it impossible to draw any other conclusion than that—at least up to 21,000 cub. ft. capacity, and 1238° temperature of blast—economy by capacity and by extra temperature are now indubitably established, and that these are not replaceable items. In other words, he deems it an established fact that—independently of the influence of high temperature of blast—up to 21,000 cub. ft. at least (indeed up to 31,000 cub. ft. capacity of furnace, as established in April 1872), a reduction of temperature of the escaping gases can be effected to such an extent as to have a direct influence on the economy of coke consumed in the furnace. At the furnace of 33,140 cub. ft. capacity, there have been recorded temperatures of the escaping gases averaging over an entire week as low as 330°, whilst the average temperature of blast over a similar period was as high as 1370°. It is further to be noted that daily records show temperatures of the escaping gases falling sometimes as low as 290° to 300°.

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The final predictions ventured upon in the paper of 1870 (page 78) were, that by increase of temperature of blast from 1422° to 1700° $\frac{3}{4}$ cwt. of coke might be saved from such increase of temperature; and that a further reduction of 2 cwt. of coke would be effected by increasing the size of the furnace to 40,000 cub. ft.; which would together reduce the ultimate consumption of coke to $17\frac{1}{4}$ cwt. per ton of iron made. No increase of temperature beyond 1422° has been attempted as a matter of regular work, so that no saving from this cause has to be recorded; indeed there have not been realised higher temperatures than 1238° as the average during 1874 at No. 1 furnace of 33,140 cub. ft., and 1288° at the other two. In the former case the saving that should have declared itself by reduction of temperature of the escaping gases from 560° to 389° might be expected to correspond to a saving of about 2 cwt. of coke per ton of iron, as arrived at by the following calculation.

The actual consumption in the furnace of 33,140 cub. ft. capacity was 21·17 cwt. of coke, whilst 19·60 cwt. only should have been consumed according to the capacity curve. The weight of the escaping gases from the furnace of 20,624 cub. ft. capacity would be, as previously ascertained for the temperature of 560°,

$$132{\cdot}4 \times \frac{21{\cdot}18}{21{\cdot}15} = 132{\cdot}5 \text{ cwt.}$$

and from that of 33,140 cub. ft.

$$132{\cdot}4 \times \frac{19{\cdot}60}{21{\cdot}15} = \underline{122{\cdot}7} \text{ cwt.}$$

$$\text{Difference} \quad . \quad . \quad 9{\cdot}8 \text{ cwt.}$$

Thus 9·8 cwt. = 1097 lb. should escape from the smaller furnace of 20,624 cub. ft. capacity at the higher temperature of 560°, whilst in addition 122·7 cwt. = 13,742 lb. should escape from the same furnace at an extra temperature of 560° − 389° = 171°.

$$1{,}097 \times 560 \times 0{\cdot}275 \text{ (specific heat)} = 168{,}938 \text{ heat-units}$$
$$13{,}742 \times 171 \times 0{\cdot}275 \quad = \underline{646{,}217} \text{ heat-units}$$
$$\text{Total} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 815{,}155$$

At 4000 units per lb. of carbon burnt into carbonic oxide, this would indicate that the probable saving which ought to be effected corresponding to reduction in temperature of the escaping gases, and assuming the correctness of the capacity curve, would be

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204 lb. of carbon, which after correction for 9·41 per cent. of impurities, would be equal to 225 lb. or 2·01 cwt. of coke.

As a matter of fact the same weight of gases has escaped from No. 1 furnace of 33,140 cub. ft. capacity, consuming 21·17 cwt. of coke, as should escape from one of only 20,624 cub. ft. capacity with the same consumption of 21·18 cwt. of coke under the former circumstances of good working; so that the actual difference between the two furnaces is only that of 132·5 cwt. of gas escaping at $560° - 389° = 171°$ lower temperature from the larger furnace. Then 132·5 cwt. $\times$ 112 lb. $\times$ 171° $\times$ 0·275 specific heat = 697,851 heat-units, which at 4000 units per lb. of carbon burnt into carbonic oxide = 174 lb. of carbon; this, after correction for 9·41 per cent. of impurities, is equal to 192 lb. or 1·71 cwt. of coke. No. 1 furnace should therefore have worked with $21·18 - 1·71 = 19·47$ cwt. of coke, in consequence of the 171° reduction in the temperature of the gases escaping from it, the result thus arrived at agreeing sufficiently nearly with the consumption of 19·60 cwt. indicated by the capacity curve for a furnace of 33,140 cub. ft. under these conditions of working. Instead however of such a result being realised in practice, the actual consumption in No. 1 furnace is 1·57 cwt. in excess of the estimated 19·60 cwt., amounting to 21·17 cwt. of coke, or the same consumption as in the furnace of 20,624 cub. ft. capacity: thus showing that the entire advantage predicted in a furnace of 33,140 cub. ft. capacity has, from causes over which no control has been possible, been sacrificed—the working capacity of No. 1 furnace of 33,140 cub. ft. having been virtually reduced to that of a furnace of only 20,624 cub. ft. capacity. That these causes have been other than the effect of combined temperature of blast and capacity of furnace, the writer trusts has been sufficiently shown. Everything points to the possibility predicted in 1870, and the writer has no doubt that the furnace of 33,140 cub. ft. capacity will yet realise in regular work the average of about 18·60 cwt. of coke per ton of No. 4 iron, as shown on the capacity curve in Fig. 8, for a temperature of 1422° of blast.

During the whole of the present year this furnace has been doing remarkably good work, weekly averages showing as low as

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19·41, 19·62, 19·67, 19·95, and 20·05 cwt. of coke per ton of iron of 3·25 quality; whilst monthly averages of 20·42 and 20·63 cwt. for 3·11 quality have been obtained. So satisfactory has been the working that a new furnace has been constructed of 33,894 cub. ft. capacity, shown in Fig. 3, Plate 57, in which it is attempted to correct a few of the defects which have perhaps contributed to some extent to the non-realisation of all that was expected in the furnace of 33,140 cub. ft. capacity. The building of another furnace of 40,000 cub. ft. capacity the writer would hardly counsel. Theoretically he believes such a capacity to be in no degree in excess of what was stated as within the limits of still saving sensible heat from the escaping gases, to the extent of the 2 cwt. of coke referred to in the paper of January 1870; but practically these large furnaces working with a minimum of coke offer such facilities for scaffolding (if not driven up to a make of at least 400 tons per week), that any slackness in the supply of materials, or any inferiority of these, whether chemical or mechanical, introduces such variations into the furnace, that the risk of scaffolding becomes serious. The writer would thus venture to affirm that there is a practical limit of capacity which will be economical, up to 30,000 to 35,000 cub. ft. in the case of good calcined Cleveland ironstone and good Durham coke; and that up to this limit both high temperature of blast and capacity of furnace will tell, together and independently of each other, in economy of fuel in the blast furnace.

It may be interesting to make a further examination of the working of Nos. 3 and 4 furnaces during the year 1874, in order to see how far the excess in consumption of 3·00 cwt. of coke per ton of iron is accounted for by the high temperature at which the escaping gases left the furnaces, namely 718°, against 560° at which they should have escaped, according to the capacity curves, had these furnaces worked at their former average of 20·78 cwt. The weight of the escaping gases with the average consumption of 23·78 cwt. of coke in 1874 would be

$$132{\cdot}4 \times \frac{23{\cdot}78}{21{\cdot}15} = 148{\cdot}8 \text{ cwt.}$$

and with the former consumption of 20·78 cwt. it would be

$$132{\cdot}4 \times \frac{20{\cdot}78}{21{\cdot}15} = 130{\cdot}0 \text{ cwt.}$$

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Hence it follows that at the same furnaces, under different conditions of temperature of the escaping gases, 148·8−130·0=18·8 cwt. more gas has passed away at the higher temperature of 718°, whilst in addition 130·0 cwt. has passed away at an extra temperature of 718°−560°=158°.

18·8 × 112 × 718° × 0·275 (specific heat)	=415,750	heat units		
130·0 × 112 × 158° × 0·275	,,	=632,632	,,	,,
Total . . .		1,048,382	,,	,,

At 4000 units per lb. of carbon burnt into carbonic oxide, this represents 262 lb. of carbon, or (corrected for 9·41 per cent. of impurities in the coke) 289 lb. of the impure coke, towards 3·00 cwt. or 336 lb., the actual excess recorded.

The table already given shows the average working of all the furnaces at the Ormesby Iron Works during the first eight months of 1875; from which it will be seen that the actual coke consumption at the furnace of 33,140 cub. ft. capacity has now fallen to within 0·94 cwt. of the theoretical amount, namely to 20·69 cwt., against 19·75 cwt. calculated according to the heat and capacity curves; but a decidedly greyer quality of iron has been produced, by three-fourths of a No., on which probably ½ cwt. of coke should be allowed, and in addition the coke has contained no less than 8·99 per cent. of impurities. Supposing only ½ cwt. be allowed for these contingencies, it will be seen that the furnace of 33,140 cub. ft. capacity has fairly worked within 0·44 cwt. of its calculated duty; and according to the capacity curves in Fig. 8 it has thus yielded an effective duty of a furnace of 28,500 cub. ft. capacity over the entire period of eight months.

In the course of this long investigation into the effective working capacity of furnaces, the writer has been led to conclude that there is an unmistakeable source of falling off in the working of blast furnaces not securely cased in iron, which has hitherto been overlooked, and which in such furnaces is the source of increasing loss the longer a furnace has been in blast. He refers to the

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insensible leakage, if it may be so called, of the gases from the sides of the furnaces, through such small cracks and fissures, that, except under special circumstances, no ignition can take place to reveal the loss which is going on. Not only has the correctness of this surmise been shown in the course of this paper, but on one occasion the writer had the opportunity of discovering the unseen leakage practically, when preparing the furnaces about eighteen months ago for a long stand. The filling with coke was proceeding, and the gases were becoming richer every hour; when suddenly, whilst standing in full view of one of the furnaces, a sudden explosion occurred in his presence, followed by minor ones, somewhat like a succession of musketry firing, and immediately the whole exterior of the furnace, at almost every hole left in the casing for drying purposes, was alight with a pale blue flame, which continued to burn until the blast was taken off the furnace. The writer feels assured that this is a continual source of loss in blast furnaces of this type, when a few years have elapsed since their erection, and both shell and lining have become somewhat disturbed; and that, coupled with irregular wear of the boshes and lining of the furnaces (which have been in blast 7¾ years), it mainly accounts for the extra consumption of about 3 cwt. of coke now going on in the furnaces of 20,624 cub. ft. capacity. Consequently he is strongly in favour of preventing any such leakage in future by the adoption of wrought-iron casings.

There is another important point which has been established in the writer's experience of the last five years, and that is the necessity in these large furnaces of a suitably increased pressure of blast to overcome the increased obstacles due to a higher column of materials. The largest furnace has within the present year turned out as much as 487 tons in a single week, of 2·76 quality of iron, and is evidently capable of a much larger production by a still further increase of volume and pressure of blast beyond 4 lb. per sq. in. at the tuyeres.

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APPENDIX.

The weight of escaping gases per ton of pig iron made may be calculated as follows, according to the mode of investigation given in Grüner's "Studies of Blast-Furnace Phenomena," Gordon's translation, pages 16 and 46.

Let a=cwt. of carbon in coke consumed, per ton of pig.
  b= do. in limestone do. =12 per cent.
  p= do. in escaping gases do.

Then, the carbon in the pig being (say) 3 per cent. or 0·60 cwt. per ton,

$$p=a+b-0\cdot60 \text{ cwt.}$$

Let y=cwt. of carbonic oxide (CO) in escaping gases, per ton of pig
  my= do. carbonic acid (CO_2) do. do.

m being the ratio by weight of CO_2 to CO in the escaping gases, as ascertained by analysis of the escaping gases at each individual furnace. Now in carbonic oxide ($CO=12+16=28$) the proportion of carbon is $\frac{12}{28}=\frac{3}{7}$; and in carbonic acid ($CO_2=12+2\times16=44$) the proportion of carbon is $\frac{12}{44}=\frac{3}{11}$. Hence $p=\frac{3}{7}y+\frac{3}{11}my$, and consequently

$$y=\frac{77p}{33+21m}$$

Let x=cwt. of oxygen in blast, per ton of pig
  d= do. in ore and limestone, per ton of pig.

Then, since in CO the proportion of oxygen is $\frac{16}{28}=\frac{4}{7}$, and in CO_2 the proportion of oxygen is $\frac{32}{44}=\frac{8}{11}$, it follows that $x+d=\frac{4}{7}y+\frac{8}{11}my$; and consequently

$$x=\frac{y}{77}(44+56m)-d=\frac{44+56m}{33+21m}\times p-d.$$

To find x the value of d must first be ascertained. If only oxide of iron (Fe_2O_3) were reduced, d would consist of the oxygen united to the carbon b in the limestone, together with the oxygen combined with 97 per cent. of the iron in the ore, the pig containing 97 per cent. of iron and 3 per cent. of carbon. Now in oxide of iron

($Fe_2O_3 = 2 \times 56 + 3 \times 16 = 112 + 48$) the ratio of oxygen to iron is $\frac{48}{112} = \frac{3}{7}$; hence

$$d = \frac{8}{3}b + \frac{3}{7} \times 0{\cdot}97 \times 20 \text{ cwt.} = \frac{8}{3}\,b + 8{\cdot}31 \text{ cwt.}$$

Pig iron contains other ingredients, such as silicon, phosphorus, sulphur, &c., which combine with oxygen in different proportions from what iron does; but the correction for these will only slightly alter the value of d (*see* Grüner, Gordon's translation, page 18). The value of x can then be calculated from that of d.

Also since air, as supplied for the blast, consists approximately of 3·33 of nitrogen to 1·00 of oxygen, the weight of nitrogen in the blast per ton of pig will be 3·33 x.

The following is the application of the above formulæ to ascertain the weight of the escaping gases in the case of the consumption of 21·15 cwt. of coke and 12½ cwt. of limestone per ton of iron made at the Ormesby Iron Works:—

Coke consumed per ton of pig		= 21·15 cwt. × 0·915*	= 19·35 cwt.	of pure carbon	= a
Limestone	do.	= 12·50 cwt. × 0·12	= 1·50 cwt.	do.	= b
Ironstone	do.	= 48·80 cwt.			
Slag produced	do.	= 29·70 cwt.			

Temperature of Blast 1251° Temperature of Escaping Gases 711°

Weight of Carbon in escaping gases $= p = a + b - 0{\cdot}60 = 20{\cdot}25$ cwt.

$$\text{Ratio } \frac{CO_2}{CO} = m = 0{\cdot}542,$$

assuming the analysis of the escaping gases to be the same as given by Grüner (page 46), though there is liability to a little error in doing so.

Weight of CO $= y = \frac{77\,p}{33 + 21\,m} = \frac{77 \times 20{\cdot}25}{33 + 21 \times 0{\cdot}542} = \frac{1559{\cdot}25}{44{\cdot}382} = 35{\cdot}13$ . . . . 35·13 cwt.

Weight of $CO_2 = m\,y = 0{\cdot}542 \times 35{\cdot}13 = 19{\cdot}03$ . . . . 19·03 cwt.

$$d = \frac{8}{3}\,b + 8{\cdot}31 = \frac{8}{3} \times 1{\cdot}50 + 8{\cdot}31 = 12{\cdot}31 \text{ cwt.}$$

$$x = \frac{44 + 56\,m}{33 + 21\,m} \times p - d = \frac{74{\cdot}352}{44{\cdot}382} \times 20{\cdot}25 - 12{\cdot}31 = 21{\cdot}61 \text{ cwt.}$$

Weight of Nitrogen $= 3{\cdot}33\,x = 71{\cdot}96$ . . . . 71·96 cwt.

Water given off from coke, say 2⅝ per cent. of 21·15 cwt. . . . . 0·56 cwt.

Total weight of moist gas per ton of pig . . . . 126·68 cwt.

* Allowing for 8½ per cent. of ash &c.

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Mr. COCHRANE remarked that he wished to bring prominently forward by the paper the importance of reduction in the temperature of the escaping gases, as it had been this object which had led him to venture upon the construction of the large furnace of 40,500 cub. ft. capacity, in order that more of the sensible heat contained in the gases might be absorbed by the materials charged into the furnace. The results predicted in the former paper in 1870 had since been confirmed by those obtained at the Newport Iron Works, Middlesbrough, where it had been stated by Mr. Samuelson in 1872 that a furnace of 30,000 cub. ft. capacity had then been working with an average consumption of 20·35 cwt. of coke per ton of iron made, the temperature of the blast being 1100° Fahr., and that of the escaping gases 462°. At those works however the minimum temperature of the gases had not been reached which had been obtained at the Ormesby Iron Works. According to the heat and capacity curves referred to in the paper the consumption of coke per ton of iron made in a furnace of 30,000 cub. ft. capacity with blast at 1050° would be about 20·50 cwt., which was thus sufficiently nearly confirmed by the consumption of 20·35 cwt. with the alleged temperature of blast of 1100° at the Newport furnaces.

In illustration of the statement that the economy due to increased capacity of furnace and the saving effected by extra temperature of blast were not replaceable items, a comparison might be made between the former good working of furnaces of 20,624 cub. ft. capacity, as described in 1870, and the recorded working of one of 33,140 cub. ft. capacity during eight months of 1875. In the former case, with a temperature of blast of 1422° and gases escaping at 560°, the furnace worked with 20·10 cwt. of coke per ton of iron made. In the latter, with a temperature of blast of 1210° (being 212° lower) and gases escaping at 374°, the furnace of larger capacity worked with 20·69 cwt. of coke, or only ½ cwt. more. Here clearly the reduced temperature of blast had been approximately compensated for by increased capacity of furnace and correspondingly reduced temperature of escaping gases. What he wished to urge therefore was that the addition of 212° to the temperature of blast at the larger furnace ought to effect a saving of 1½ cwt. of coke, as

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indicated by the curve of blast temperature; so that temperature of blast should tell in economy, in addition to and beyond what was due to capacity of furnace.

As regarded the average temperature of blast—only 1238° over eight months' working of the furnace of 33,140 cub. ft. capacity in 1874,—this was by no means an adequate indication of what the hot-blast stoves were capable of doing. The recorded averages of two or three months out of the eight showed the temperature of the blast to have approached more nearly 1400°, whilst daily averages frequently occurred of about 1500° and occasionally exceeded 1600°; the stoves were indeed capable of heating the blast up to 1700° as easily as up to 1200°.

In furnaces exceeding 10,000 or 12,000 cub. ft. capacity he looked upon the temperature of the escaping gases, measured by the pyrometer, as the very pulse of the furnace; by that means the extent of scaffolding within the furnace could be measured in cubic feet, and it could be seen whether the filling at the furnace top was being properly done.

Mr. I. Lowthian Bell said that to the author of the paper now read undoubtedly belonged the merit of being one of the first among English ironmasters to draw attention to the economy consequent upon the employment of high blast-furnaces; and he had added to the obligation previously conferred by now bringing forwards most ingenuously the results of his more recent experience, stretching from 1869 to 1875. But the conclusions arrived at in the paper were so opposed to the opinions he had himself formed on the same subject, that he was compelled to dissent strongly from the inferences which had been there drawn from the facts as stated.

Practically it appeared to him that four conclusions were to be inferred from the statements given in the paper:—First, that it was possible by increasing the capacity of the furnace to effect such a reduction in the temperature of the escaping gases as to bring down the consumption of coke per ton of iron smelted from Cleveland ironstone from 26·52 cwt. to 18·60 cwt.; indeed less than 18·60 cwt. had been hinted at and declared probable on former occasions.

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Secondly, that there were certain curves of furnace capacity and of blast temperature, which indicated the corresponding consumption of coke. Thirdly, that it was possible to smelt Cleveland ironstone with 18·60 cwt. of coke per ton of iron made. Fourthly, that the capacity of the furnace and the temperature of the blast were not replaceable items.

In contradistinction to these conclusions, the results of his own experience in the working of blast furnaces had led him to the following:—First, that it was a physical impossibility by any increase in the size of the furnace to cool the escaping gases down to so low an average temperature as 120° Fahr., as supposed in the paper to be possible. Secondly, that no such curves existed as those laid down in the diagrams exhibited, representing the relation between furnace capacity or blast temperature and consumption of coke. Thirdly, even supposing it were possible to cool the escaping gases to 120°, that there were natural laws which rendered it impossible to smelt a ton of iron from Cleveland ironstone with so small a quantity as 18·60 cwt. of coke. Fourthly, that the capacity of the furnace and the temperature of the blast were, within certain limits, strictly replaceable items.

The source of heat in a blast furnace was threefold. There was first that due to the conversion of carbon into carbonic oxide; second, the heat introduced with the blast; and third, that evolved by the conversion of carbonic oxide into carbonic acid. The actual proportions on one occasion, as ascertained by his own experiments, were 48·2 per cent. from the first source, and 12·8 per cent. from the second, leaving 39·0 per cent. as the proportion of heat due to the conversion of carbonic oxide into carbonic acid.

This conversion of carbonic oxide into carbonic acid being strictly confined to the upper part of the furnace, the question naturally arose, what became of the heat generated near the furnace top, as it was not apparent to the ordinary modes of measuring temperatures. The fact was that it was absorbed by the duties it had to perform; for it had to effect firstly the conversion of oxide

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of iron into metallic iron, and secondly the expulsion of the carbonic acid from the limestone. Although therefore the contents of a blast furnace near the charging plates were far from being at a red heat, he considered it hazardous to assume that after the duties just mentioned had been performed there was any actual increase of heat, due to the reduction of oxide of iron by carbonic oxide. For it had been affirmed that the reduction of oxide of iron very nearly but not quite absorbed all the heat generated by the carbonic oxide required for this reduction passing into the state of carbonic acid; and that there were thus grounds for supposing that an actual elevation of temperature took place, due to chemical action. In order however that so important a question might not be left to mere speculation, he had had recourse to experiment for settling a matter about which even able chemists were somewhat doubtful. In this trial the whole of the ironstone being withdrawn from the charges of a blast furnace, he had substituted in its place a neutral substance,—neutral so far as concerned any chemical action between it and the escaping gases. For this purpose a mixture of flints and blast-furnace cinder was selected, the specific heats of these materials having in the first place been ascertained to coincide almost precisely with the specific heat of the ironstone which they were intended to replace. The result of the change was found to be that the average temperature of the escaping gases, which had previously been 782°, within forty minutes after the flints and cinder were substituted for the ironstone did not exceed 560°, soon afterwards it fell to 464°, above which figure the thermometer never rose during 3½ hours further continuance of the experiment. The flints and cinder were then discontinued, and the original charge of ironstone resumed. An immediate rise in the temperature of the escaping gases on reverting to ironstone was not to be expected, because time was required for the oxide of iron to become sufficiently heated to allow of chemical action commencing. At the end of one hour the temperature of the escaping gases had risen from 464° to 500°, in the next forty minutes to 581°, and in thirty minutes more to 700°. This appeared to him to prove that there was an absolute evolution of heat going on at the top of a

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blast-furnace; in other words the heat generated by the formation of carbonic acid exceeded that absorbed by the reduction of the ore.* By this means in his opinion did the heat creep to the top, whatever might be the height of the structure. This view of the subject might be illustrated by the diagrams, constructed from actual observation, shown in Fig. 9, Plate 59, in which the depth of shading would serve to convey an idea of the relative temperatures of the contents of a blast furnace: at a height of say 45 ft. in the smaller furnace of only 48 ft. total height the materials were black, no signs of incandescence being visible; whereas the materials at the same height in the 80 ft. furnace were at a bright red heat, and were not black until reaching a height of about 70 ft. from the hearth.

In the paper it appeared to have been expected that the furnace of 40,500 cub. ft. capacity would cool the escaping gases down to 120° Fahr., whereas in actual working they were not got below 428°. In matters of this kind it was of course advisable to base conclusions upon comprehensive observation, not confined to the conduct of one single blast furnace; and at the different works belonging to his own firm at Middlesbrough and elsewhere he had had an opportunity of studying the behaviour of fifteen blast furnaces—two of 11,500 cub. ft. capacity, two of 11,600, two of 15,400, one of 17,500, four of 22,000, and four of 25,500 cub. ft. capacity. If therefore the curve referred to in the paper as exhibiting the cooling power of furnaces of different dimensions could be maintained, he might claim to have had an opportunity of making the discovery in these fifteen furnaces having capacities ranging from 11,500 to 25,500 cub. ft. In these several furnaces however there was no practical difference in the temperature of the escaping gases; and consequently the curve drawn to exhibit the cooling effect of an increase in the size of furnaces, above say 12,000 or 14,000 cub. ft. capacity, appeared to him to be fallacious.

* To avoid complicating the argument, the small quantity of carbonic acid due to carbon deposition is not separated here from that produced by reduction of the ore.

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If any of the heat generated in the blast furnace was not utilised for the reduction of the materials, the most natural place to look for it was of course in the escaping gases; and in the paper the endeavour had been made to show by calculation that a certain amount of surplus heat was actually to be found going away to waste in the escaping gases. In these calculations however it appeared to him that some serious errors were involved. Assuming that the quantity of heat given out by the combustion of the coke was constant, and, as was no doubt really the case, that the quantity of heat absorbed by the work to be done was also practically constant, then the heat passing off in the escaping gases might truly be the difference between these two quantities. But in calculating the amount of this difference, as was done in the paper, it was assumed in the first place that the specific heat of the escaping gases was 0·275; instead of which he believed the specific heat of such a mixture of gases as that escaping from a blast furnace had been found by the most recent chemical investigations to be about 0·24; hence in the first of the calculations contained in the paper this correction would give 835,000 instead of 957,000 total heat-units as the quantity of wasted heat passing off with the escaping gases in the instance in question. In the next place the number of heat units evolved by the combustion of 1 lb. of carbon into carbonic oxide had been assumed to be 4,000; whereas he was not sure that 4,320 was not nearer the correct number. Allowing 4,000 to stand however, as near enough to the truth, it was further to be remarked that no notice had been taken of the fact that the coke was burnt on that occasion with blast having a temperature of 1670°; so that, instead of dividing the larger number 957,000 by 4,000, he considered that the smaller number 835,000 ought to have been divided by about 5,670; and the result, instead of accounting for nearly the whole deficit of heat in the working of the furnace, would in reality account for only something like half of it. The same mistake appeared to be involved in the other calculations contained in the paper.

It was however a serious error to assume that the heat evolved by the coke was constant; on the contrary he believed it to be very

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variable in amount, for in his own experience he had found the difference between a large and a small furnace to amount to as much as 18 per cent. in this respect alone, and as a matter of fact it was subject to considerable fluctuations in all furnaces. This difference was due to the varying quantities of carbonic acid found in the gases. Before proceeding therefore to estimate the difference between the heat evolved by the coke and the heat absorbed in the work of the furnace, it was necessary that the actual quantity of heat produced by the coke should be determined in the particular instance under consideration; and of the variation in this quantity no account had been taken in the paper.

To save 8 cwt. of coke per ton of iron by cooling the escaping gases he believed to be an impossibility, even supposing their temperature were reduced to the freezing point of water; for they did not contain sensible heat equivalent to that weight of fuel. Even supposing it were possible to intercept all the heat contained in the gases, he considered it could be shown that no benefit after a certain point would be gained thereby.

With regard to the curves laid down as the guides which had led to the conclusions arrived at in the paper, it had been assumed that in a furnace of 20,000 cub. ft. capacity the actual consumption in regular working was 26 cwt. of coke per ton of iron made; but he did not think ironmasters in general would agree in this being the proper consumption of fuel in a furnace of that capacity when working satisfactorily. In determining the path of a curve which was intended to indicate what was possible in the future by showing what had been done in the past, it was of the greatest importance that the points denoting what had been done in the past should be correctly marked. Supposing that the proper consumption of coke per ton of iron made in a furnace of 20,000 cub. ft. capacity were the 26 cwt. assumed in the paper, and that a furnace of 25,000 cub. ft. were able to perform the same duty with 25 cwt.; then these two numbers being plotted upon a properly divided

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diagram, it was clear that, unless a line drawn from one point to the other turned very abruptly at or soon after leaving the point of 25 cwt., there was a high probability that some saving would follow a further increase of capacity say up to 30,000 cub. ft. But supposing on the other hand, as he had found to be the case in the performance of furnaces ranging from 6,000 to close upon 26,000 cub. ft., that the data given in the paper, although correct in the instance of the particular furnaces there referred to, were not by any means of general application, what became of the curve of so-called effective capacity, laid down from those data? By doubling the capacity of a furnace of 6,000 cub. ft., without any alteration in the temperature of the blast, he had found that the consumption of coke per ton of iron made could be reduced from 29 cwt. to about 22 cwt.; and it was therefore obvious that a curve, constructed upon two such starting points as these, must follow a very different path from that based upon the figures given in the paper. He had proved indeed that a furnace of 12,000 or 15,000 cub. ft. capacity could make a ton of iron with 4 cwt. less coke than the quantity given in the paper as having been required in a furnace of 20,000 cub. ft., even when using a lower temperature of blast than that employed in the Ormesby furnaces; and that any further increase of size had been attended with no marked economy in fuel. In regard to his own curve of fuel consumption as determined by capacity of furnace, which had been referred to as confirmatory of the views advanced in the paper, that curve had been laid down in 1869, but subsequent experience had shown him that it could not be strictly relied on. At that time indeed he had conceived that the curve so laid down from the knowledge then possessed pointed to the possibility of reaching a consumption of only 20 cwt. of coke per ton of iron; even now he did not consider this to be altogether impossible with very good coke, and thus the opinion entertained even so far back as 1869 could not be regarded as having been very far from the truth.

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By applying the curves laid down in the paper to a furnace of 40,500 cub. ft. capacity, blown with air at 1142°, it was inferred that the theoretical proper consumption of coke under those conditions was 20·50 cwt. per ton of iron made, the actual consumption having been 22·75 cwt. With this theoretical result however, based on the dimensions and high temperature of blast just mentioned, he was unable to reconcile his own actual experience of having made iron over consecutive weeks with nearly as small a consumption of coke in a furnace of only 22,000 cub. ft. and with blast about 200° lower in temperature than that used in the furnace of 40,500 cub. ft. In consequence of the irregularities attendant upon the smelting of iron, it was difficult in any furnace to say what the consumption of fuel was, within ¼ cwt. per ton of iron made; and there was no occasion for surprise at the difficulties experienced in the working of the Ormesby furnaces, as described in the paper, though at the same time it appeared to him that the figures and facts given in the paper failed to prove what was the precise nature of the causes which led to the disasters mentioned. In 1871 it was stated there had been three furnaces in blast—Nos. 2, 3, and 4,—each of the two latter making 1758 tons of iron per month with blast of 1235° temperature; and during that time these two smaller furnaces of 20,624 cub. ft. capacity, as well as the larger one of 40,500 cub. ft., were nearly blocked up for want of blast. But in 1873, when in consequence of the trouble experienced with the large furnace it was blown out, and the two smaller ones went on alone he presumed with all the blast-engine power necessary for blowing three furnaces, these same two furnaces produced each 1752 tons per month, their consumption of coke being less by ¼ cwt. per ton of iron, while the blast was only 90° cooler, in 1873 than in 1871.

While the statement of the facts observed at the Ormesby furnaces was unquestionably entitled to full belief, he was certainly surprised by some of the statements made in the paper; and in dealing with questions of physical laws, he had often in his own experience met with things which he could not at the time account for, but in which he had always found that nature was right. When

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therefore it was stated in the paper that the temperature of the gases escaping from a blast furnace was as low as 330°, and sometimes even down to 300° or 290°, he concluded there must have been some disturbing cause to account for this; there was no occasion for questioning the correctness of the observation of these recorded temperatures, but there were many circumstances which would account for such changes of temperature in the escaping gases, and these circumstances demanded rigid investigation. For instance, there was no substance that exerted so immediate and so great a cooling influence as water, which in this humid climate was occasionally so plentiful; and the coke going into the furnaces referred to in the paper might at the time have been saturated with rain. In the fifteen blast furnaces at his own works he had had the temperatures of the escaping gases noted a great number of times, sometimes for twelve hours consecutively; and in the most recent experiment he had made, the lowest recorded temperature was 335°, and the highest from the same furnace 695°. If the gases at the Ormesby furnaces ever reached this same temperature of 695°, as he supposed they might be expected to do, then in order to obtain the average given in the paper of 330° they must also have been escaping for a great portion of the period nearly at zero. If on the other hand the minimum temperature was say 300°, then to obtain an average of 330° the maximum must not have exceeded 360°—a state of things which in the normal condition of blast furnaces had never occurred within his own experience.

With regard to the capacity curve referred to in the paper, the consumption of coke in the furnace of 33,140 cub. ft. capacity was stated to have been actually 21·17 cwt. per ton of iron made; and it was also stated that the furnace of 20,624 cub. ft. had produced as much iron with the same quantity of coke and with the blast at the same temperature. If the capacity curve held good, and if the difference between the effective capacities of the two furnaces was really at all proportionate to the difference between 33,140 and 20,624 cub. ft., he should be glad to hear why these two furnaces differing so considerably in size had made a ton of iron with the

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same quantity of coke. The furnace of 33,140 cub. ft. was said to have been doing remarkably good work, weekly averages showing as low a consumption as 19·41 to 20·05 cwt. of coke per ton of iron; but what he should like to know would be the average for a consecutive number of weeks, not that of one week at one time and another week at another. For it was a recognised fact in blast-furnace management that furnaces making a very rich iron and working well continued to do so for some time after the burden had been increased for obtaining a lower quality of metal. For a few days the furnace continued, even after the change of burden had reached the hearth, to make iron of much better quality than it did at the expiration of that short time. His attention had often been called to this circumstance, which he thought might be explained in the following way. Supposing the burden were increased in a blast furnace of 80 ft. height, then during its whole progress through say 25,000 cub. ft. of furnace room this heavier burden was exposed to the heat given off from the more elevated temperature prevailing at the tuyeres in consequence of the previous lighter burden. Elsewhere upon a former occasion he had called attention to an action taking place in blast furnaces,—carbonic oxide becoming resolved into carbonic acid and carbon,—which resulted in the deposition of carbon; and he had reason to believe that within certain limits, the lighter the burden, the more copious was this deposition of carbon, which was thus distributed through the whole contents of the furnace. On increasing the burden of the furnace therefore, it was not until the extra heat and the additional deposited carbon due to a pre-existing condition of things had been worked off that the furnace came to its true bearing, which in one of 33,140 cub. ft. might require nearly a week to accomplish. He could accordingly understand the consumption of coke being in this way reduced for a week to the 19·41 cwt. mentioned in the paper; and he should therefore like to have the result of the working of the same furnace not for one week but for consecutive weeks, with a statement of the consumption of ironstone, and other particulars of the work performed. In the construction of the capacity curve accompanying

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the paper he should be glad to be informed whether in comparing the furnace of 20,624 cub. ft. with that of 40,500 cub. ft. the fact had been duly regarded that in the smaller furnace the make of iron per 1000 cub. ft. capacity was as much as 79 tons per month, whereas in the larger furnace it was only 32 tons per month for the same cubic capacity.

In support of the possibility of so small a consumption of coke as had been spoken of in the paper, reference had been made to the statement of Mr. Samuelson having some years ago made iron with as little as 18·75 cwt. of coke per ton of iron. That also was the result he believed of only a single week's working, and having at the time examined the calculations he remembered that the ironstone smelted with this small consumption of coke appeared to contain $44\frac{1}{2}$ per cent. of iron; whereas he had never seen any Cleveland ironstone, though smelting 2000 tons of it per day, which contained much above 41 per cent., and the proportion was generally nearer 40 per cent. In his own experience never even by accident had the consumption approached so low an amount as 18·75 cwt. of coke per ton of iron; and he was thus obliged to draw the inference that, in the cases where such a low consumption was stated to have been realised, either there must have been some error with regard to the weighing of the coke or of the ironstone, or something must have occurred to account for the exceptional result. At any rate, in the instance furnished by Mr. Samuelson's experience, the economy stated to have been arrived at had required neither the size of furnace nor the temperature of blast propounded in the present paper as indispensable for so low a consumption of coke.

As regarded the temperature of the blast, in respect to which also curves had been laid down by the author of the paper, he still adhered to the opinion which he had very early held, that there was a temperature beyond which it was not necessary to go. Not satisfied with the experience of those who still believed the blast could beneficially be heated to 1400°, he had himself tried air of this temperature in two furnaces by means of firebrick stoves, but had found no kind of advantage from so hot a blast; and he

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believed that in a furnace of sufficient capacity blast at 900° was as good as at 1400°, or even as at 1700° if it could be obtained so hot. It was only proper to state that the furnaces upon which the trial had been made were only 65 ft. high, but his observations on their work as well as the results of other makers entitled him to hold the opinions just expressed.

The natural laws which in his opinion precluded the possibility of smelting a ton of iron in the Cleveland district with so small a quantity as 18·60 cwt. of coke were based on the following considerations. For every ton of iron smelted, there was, as stated in the paper, 6·58 cwt. of carbon converted into carbonic acid. Having made a great many experiments to ascertain whether there was a point beyond which carbonic oxide refused to take up oxygen from the oxide of iron in this ore at given temperatures, he had satisfied himself that that was the case. These experiments were not confined to short periods of time, but extended over many consecutive hours. The result thus arrived at was that, when 1 lb. of carbon had been converted into carbonic acid, it was necessary, in order to ensure its continuance as carbonic acid in the mixture of gases evolved from a blast furnace, that there should be present in that mixture 2 lb. of carbon as carbonic oxide; in other words, only one third of the carbon contained in the gases of the Cleveland blast furnaces could be made to pass into the form of carbonic acid. Consequently the 6·58 cwt. of carbon in the form of carbonic acid required the presence of 13·16 cwt. of carbon as carbonic oxide; these two figures made together 19·74 cwt. of carbon, of which 1·32 cwt. was contributed by the limestone, leaving 18·42 cwt. to be supplied by the coke. The pig iron however absorbed 0·60 cwt. of carbon, bringing up the requirement to 19·02 cwt. of carbon; and making the addition, as in the paper, for 8 per cent. of impurities in the coke, the result was not less than 20·66 cwt. of coke as the quantity required to smelt one ton of iron.

If however the extra heat introduced into a furnace by the employment of a highly heated blast was found to produce no

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beneficial effect in saving fuel, the question arose as to what became of it,—whether it was to be found in the escaping gases. As a rule this was not the case; but the cause of the disappearance of the heat he believed to be, that when carbonic acid was heated beyond a certain point it had the power of acting on carbon—of burning it in fact, by becoming itself unburnt, as it were. Thus 1 lb. of carbon in the form of carbonic acid acting on 1 lb. of fresh carbon afforded 2 lb. of carbon as carbonic oxide; this operation absorbed heat, or in other words had a cooling influence; and it was an action of this nature, he considered, which often led to the disappearance of heat in the upper region of a blast furnace. At the Clarence Iron Works he had recently had a striking case of this kind. In one of the collieries supplying these works the coal had been considerably altered by the presence of a whin dyke; it did not coke well, but was richer in fixed carbon than the unaltered coal. As soon as this coke was received at the blast furnaces the consumption rose from 20¾ to 26 cwt. per ton of iron. The coke was at once subjected to analysis, and found to contain no more ash than the best coke produced from the same collieries. According to the curve accompanying the paper, he supposed the extra consumption would have been set down to a reduction in the effective capacity of the furnace; but the real reason he believed to be that there was so small a quantity of volatile matter in the coal, that it was difficult to obtain from it coke possessing the hard character which was so valuable an attribute of Durham coke; and he had found the hard coke was much less subject to the wasting action by carbonic acid than coke of a softer description. This disturbance did not occur at one furnace only; there were two furnaces, and in both of them a consumption of 20¾ cwt. per ton of iron rose to 26 cwt., the coke itself being equal in heating power and in content of carbon to the best coke.

It appeared in the paper that on one occasion an extra consumption of coke, which could not otherwise be accounted for, had been attributed to an escape of gas through the sides of the furnace; but he could not understand how this loss, had it occurred under ordinary circumstances, could have been unnoticed, because wherever

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the furnace gas escaped it left a white mark at the point of exit. It was recommended in the paper that any such escape should be prevented by casing the furnace carefully with iron; this however was impracticable, because unless a space was left between the casing and the outside of the furnace the former was sure to give way in consequence of the expansion of the brickwork within: indeed latterly he had on this account discarded casings altogether. But he considered no such danger of escape of gas was really to be apprehended. With the view of ascertaining the condition of the contents of a furnace while working, he had had one of the furnaces at his works pierced at every 6 ft. height from bottom to top with an aperture 6 in. square, and the greatest difficulty had been experienced in keeping these 6 in. holes open; for they invariably became closed by the fused matter present among the materials under treatment. The reason of the explosion referred to in the paper was stated to have been that the gas was richer in carbon after discontinuing the ironstone when preparing for a long stand; but it must be borne in mind that the chemical change which in the regular working of a furnace rendered the gas less rich in combustible matter took place at the top, while below a depth of 15 ft. down or thereabouts the carbon-gas in the furnace was wholly carbonic oxide, without any admixture, practically speaking, of carbonic acid; and consequently the gases could not there be rendered richer in combustible matter by any reduction of the burden. In point of fact therefore, whether any ironstone was being charged or not, no practical difference was thereby made in the explosive nature of the gas throughout by far the greater portion of the contents of the furnace. For when carbon was burnt with atmospheric air it was impossible to get gas containing more than about $34\frac{1}{3}$ per cent. of carbonic oxide, the remainder being atmospheric nitrogen; and this he had found to be the composition of blast-furnace gases, excepting in something like 15 ft. height at the upper part of the furnace. It had indeed been mentioned in the paper that the flame observed outside the furnace succeeded an explosion; and he could understand that this furnace, though hermetically

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sealed previously, showed flame in consequence of the shock of the explosion creating numerous fissures, through which then a quantity of gas might easily escape.

In reference to the extent to which temperature of blast and capacity of furnace were capable of replacing each other, it had to be observed that, whereas in a cold-blast furnace the heat was produced practically by the combustion of carbon alone, in a hot-blast furnace say of 48 ft. height 86 per cent. of the heat might be regarded as produced by the combustion of carbon and 14 per cent. as introduced by the blast. Every lb. of carbon burnt at the tuyeres required the same quantity of air, whether the blast were hot or cold; but in the case supposed of the hot-blast furnace 14 per cent. of the heat was not the product of fuel burnt *in* the furnace, but was brought in by the blast. Consequently the volume of gas produced to obtain the same quantity of heat was less when using hot blast than when the entire heat was the product of carbon burnt at the tuyeres. This of course was equivalent to an enlargement of the furnace, inasmuch as a given volume of the hot reducing gases remained a longer period of time in a furnace driven by hot blast than in one blown with cold air. A case which he had mentioned on a former occasion served to illustrate how temperature of blast could be replaced by capacity of furnace, and vice versâ. At the Lilleshall Iron Works the furnaces of 53 ft. height required a consumption of 40 cwt. of coke for smelting a ton of iron with cold blast, and only 28 cwt. when employing hot blast; but on the cold-blast furnaces being raised to 71 ft. height their consumption fell to 28 cwt., the same as in the hot-blast furnaces of 53 ft. height. It was clear therefore that capacity of furnace and temperature of blast were mutually replaceable, at all events within the limits of furnaces described in the paper.

The foregoing were his reasons for differing from the opinions advanced in the paper as to the possibility of making a ton of iron with 18·60 cwt. of Durham coke, when smelting Cleveland ironstone

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under the conditions which now prevailed. The question was one to which he had paid some attention; and acceptable as further economy would be in the present depressed times, he could not bring himself to believe that the hope entertained in the paper stood much chance of being realised.

Mr. E. A. Cowper said he looked upon the curves accompanying Mr. Cochrane's paper of 1870 as substantially correct; they were borne out by practical experience, and the results obtained at other works did not in any way contradict them. The consumption of coke for some time previously to 1870 had been commonly from 24 to 28 cwt. per ton of iron, and this had been reduced to 20·1 cwt. by the application of hot blast of 1422° temperature in a furnace of 20,624 cub. ft. capacity. The effect due to the increased size of the furnace from 20,624 cub. ft. to 33,140 cub. ft., with a lower temperature of blast, namely 1210°, was to reduce the consumption to 20·69 cwt. per ton of iron; these were facts directly bearing upon the curves of capacity and temperature. During the whole month of April 1872 the furnace of 40,500 cub. ft. had worked with only 18·93 cwt. of coke per ton of iron, the temperature of the blast being 1385°; and if the temperature of the blast were further increased, he was satisfied the consumption would be somewhat lower still. At other works he knew the consumption of coke per ton of iron made had been reduced 4 or 5 cwt., and in one instance as much as 7½ cwt., solely in consequence of the increased temperature of the blast; in a furnace making best Bessemer pig the saving by the hotter blast had amounted to 36 per cent., the actual consumption being only 18·46 cwt. of coke per ton of iron made. At the Creusot works, where there were twenty-five of his hot-blast stoves, and at the Ebbw Vale works also, the consumption had now been brought down very low by the use of hotter blast. Another important result with the higher temperature of blast was the large increase in the make of iron, amounting at some furnaces to 20, 30, and even 37 per cent. increase of make; and this was to be expected, and followed from the saving of fuel per ton of iron, for if the same quantity of fuel was continued to be

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burnt, it followed that more iron was made from it. Thus small furnaces with a high temperature of blast competed successfully with large furnaces working with the ordinary temperature of blast.

The discussion was then adjourned to the following meeting.

The Meeting then terminated.

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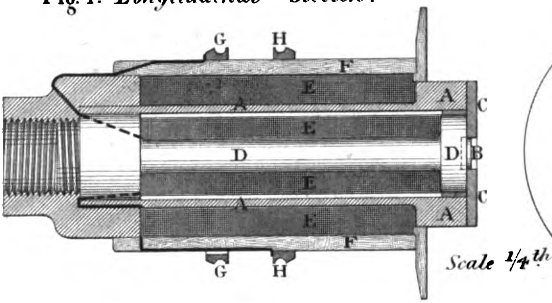
ELECTRO-MAGNETIC CHUCK. *Plate 1.*

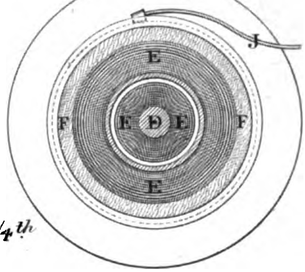
Lathe Chuck.

Fig. 1. *Longitudinal Section.*



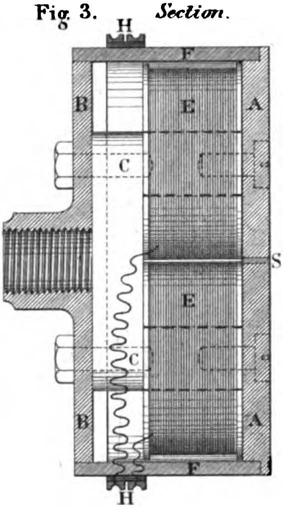
Scale 1/4th

Fig. 2. *Transverse Section.*



Chuck formed with Horse-shoe Magnet.

Fig. 3. *Section.*



Scale 1/8th

Fig. 4. *Face View.*

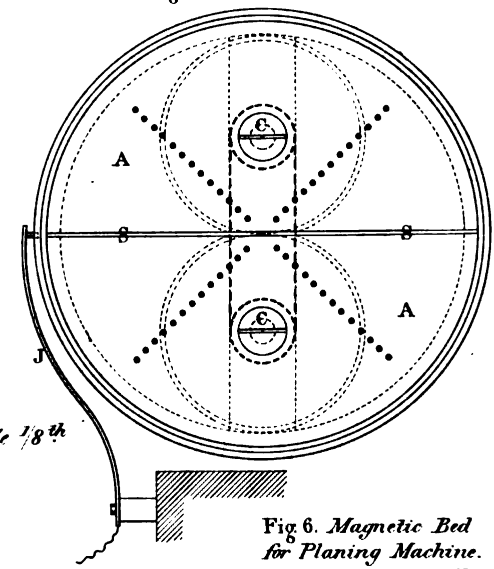
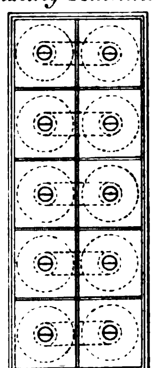
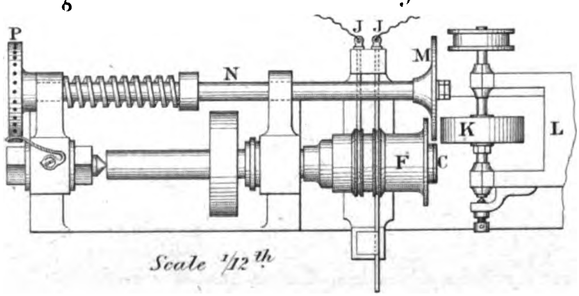


Fig. 6. *Magnetic Bed for Planing Machine.*



Scale 1/24th

Fig. 5. *Plan of Lathe with Magnetic Chuck.*



Scale 1/12th

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PORTLAND CEMENT MANUFACTURE.

Plate 2.

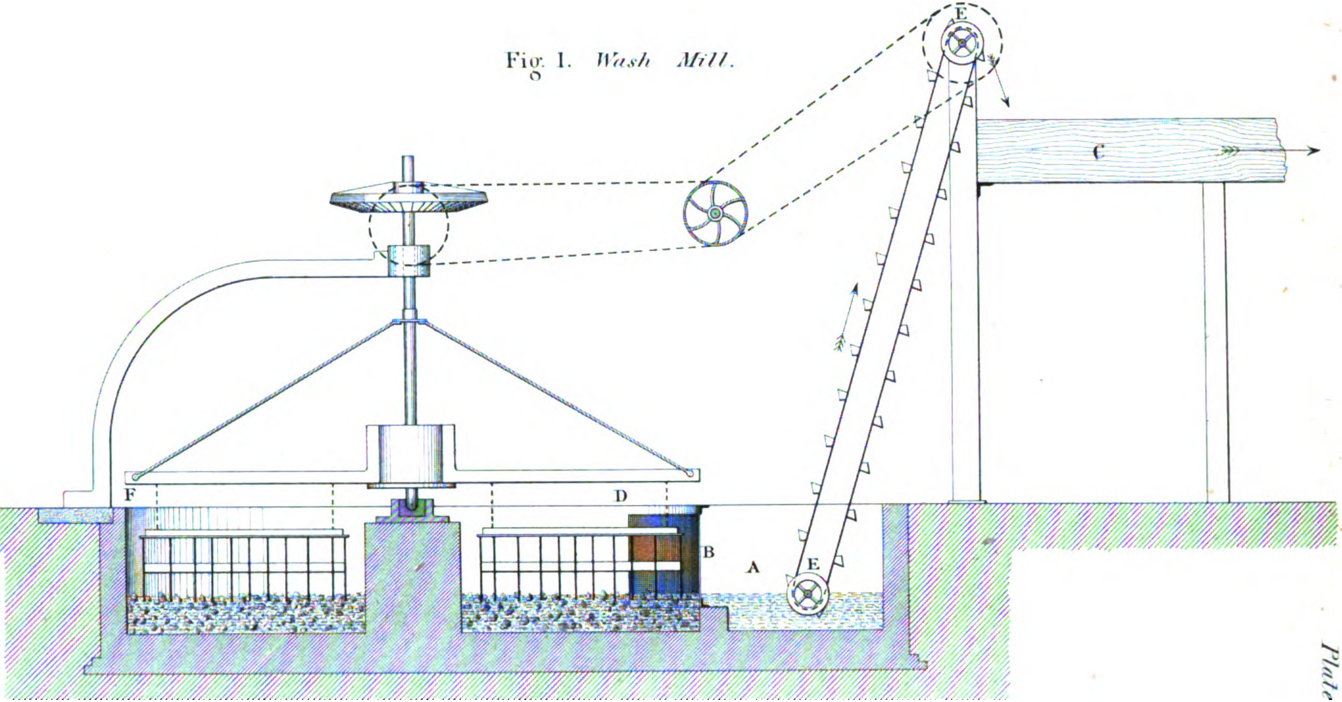

Fig. 1. *Wash Mill.*

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PORTLAND CEMENT MANUFACTURE.

Plate 3.

Settling Back.

Fig. 2. *Transverse Section.* Scale 1/240th.

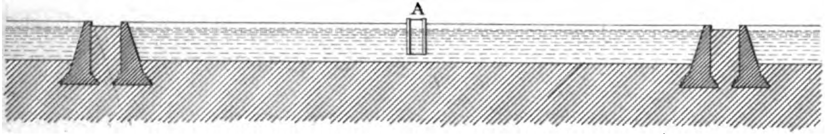
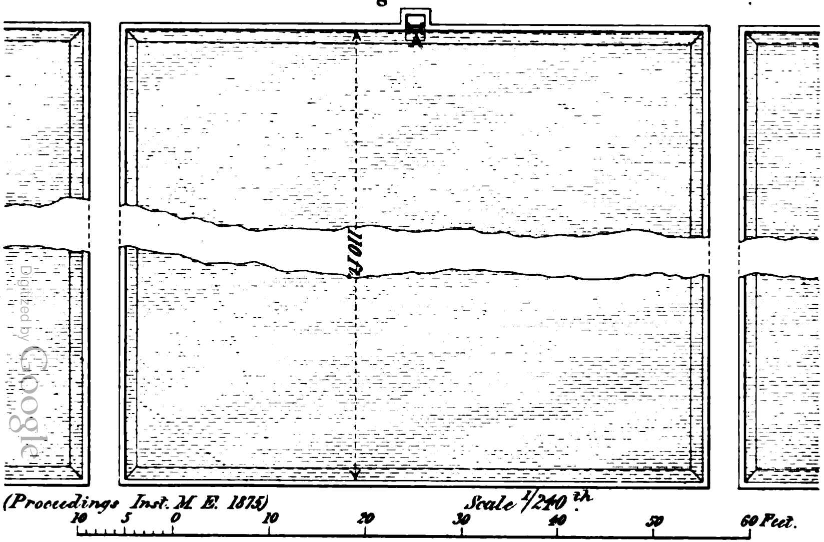


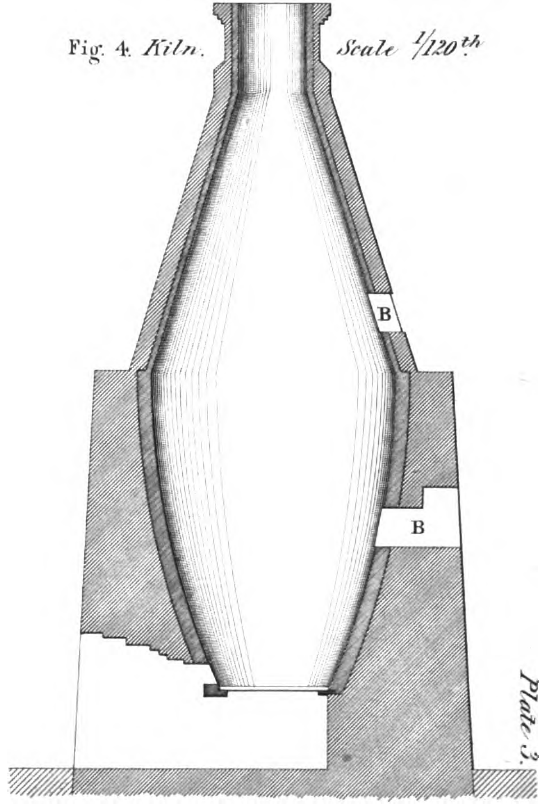
Fig. 3. *Plan.*



(Proceedings Inst. M. E. 1875)

Scale 1/240th.

Fig. 4. *Kiln.* Scale 1/120th.



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PORTLAND CEMENT MANUFACTURE.

Drying Floor.

Fig. 5. Longitudinal Section.

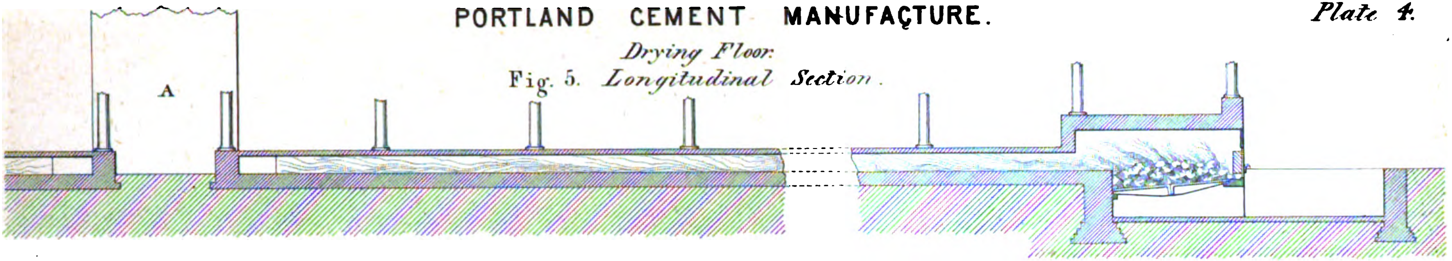
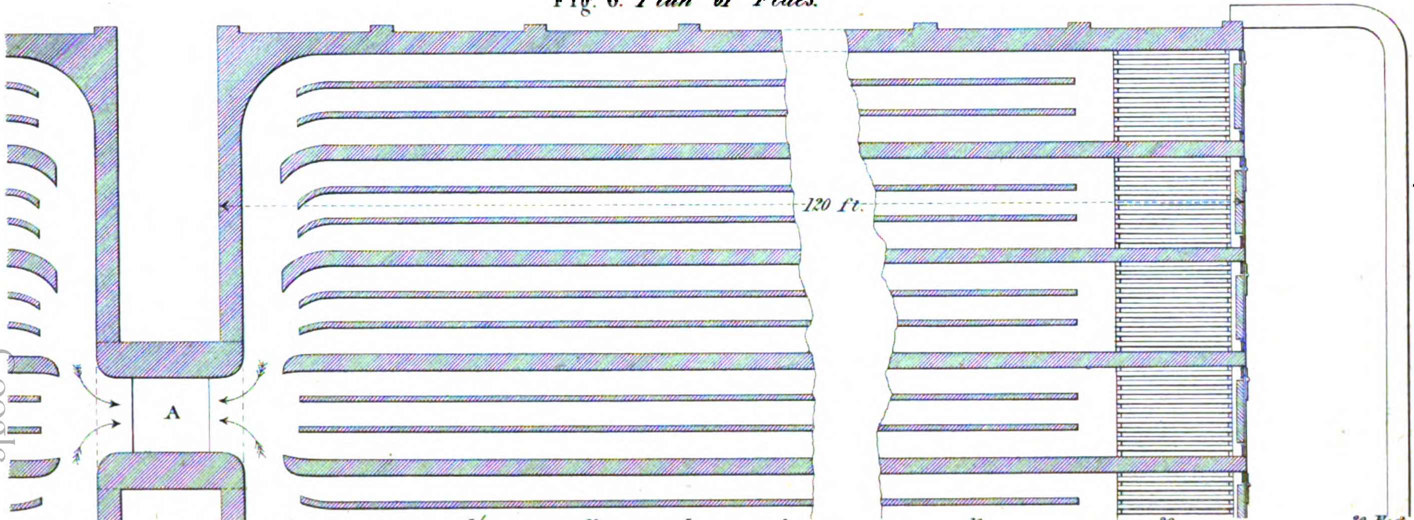


Fig. 6. Plan of Flues.



(Proceedings Inst. M. E. 1875.) Scale 1/120th

Plate 4.

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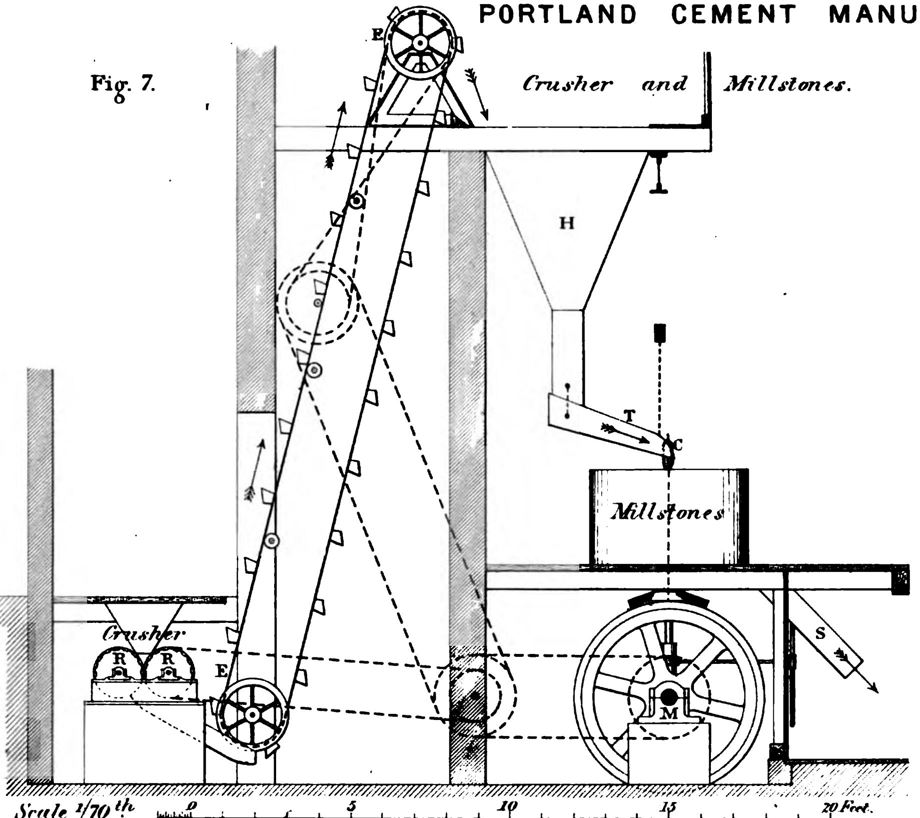
PORTLAND CEMENT MANUFACTURE.

Fig. 7.

Crusher and Millstones.



Scale 1/70th.

Testing Briquette.

Fig. 8.

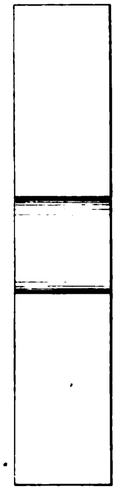
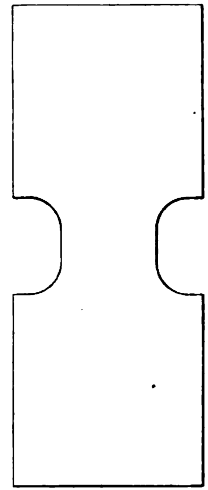


Fig. 9.



Scale one third full size.

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Plate 5.

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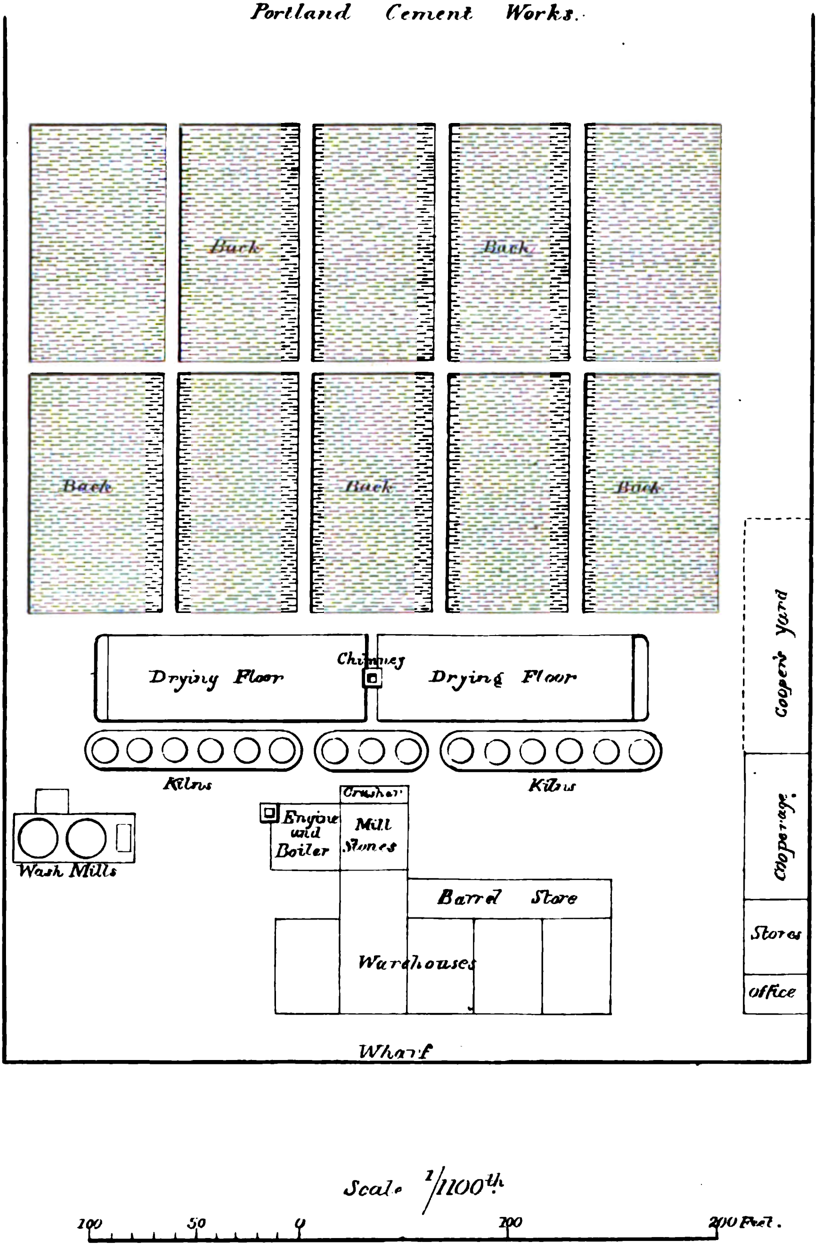
Fig. 10. *General Plan showing arrangement of Portland Cement Works.*



(Proceedings Inst. M. E. 1875)

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Plate 7.

RAILWAY GAUGE.

Fig. 1. *Common Road Vehicle.*

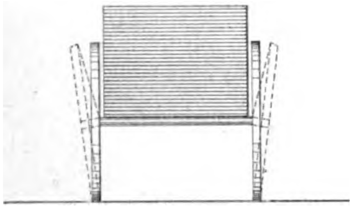


Fig. 2. *First Railway Wagon on Tramroad or Edge Rail.*

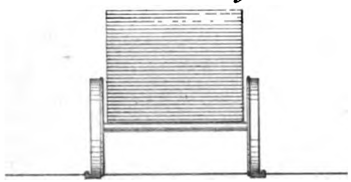


Fig. 3. *Present Railway Chaldron Wagon.*

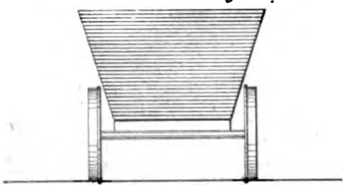


Fig. 4. *Early enlarged Railway Carriage.*

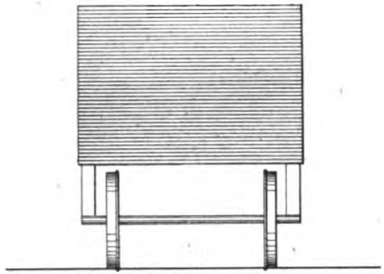


Fig. 6. *Present enlarged Carriage 4'·8½" Gauge.*

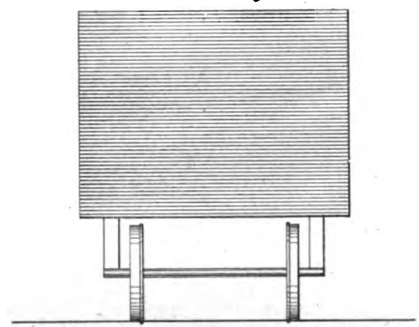


Fig. 5. *Original intended Carriage 7'·0" Gauge.*

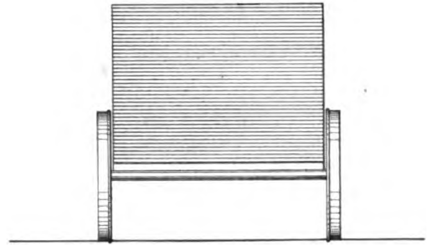
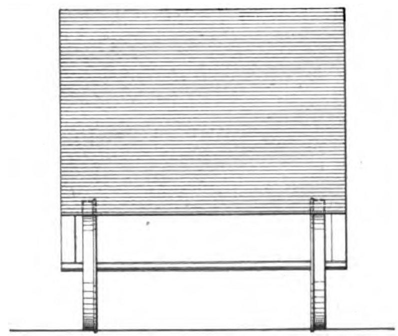


Fig. 7. *Present enlarged Carriage 7'·0" Gauge.*



(Proceedings Inst. M. E. 1875) *Scale 1/70th.*

Plate 7.

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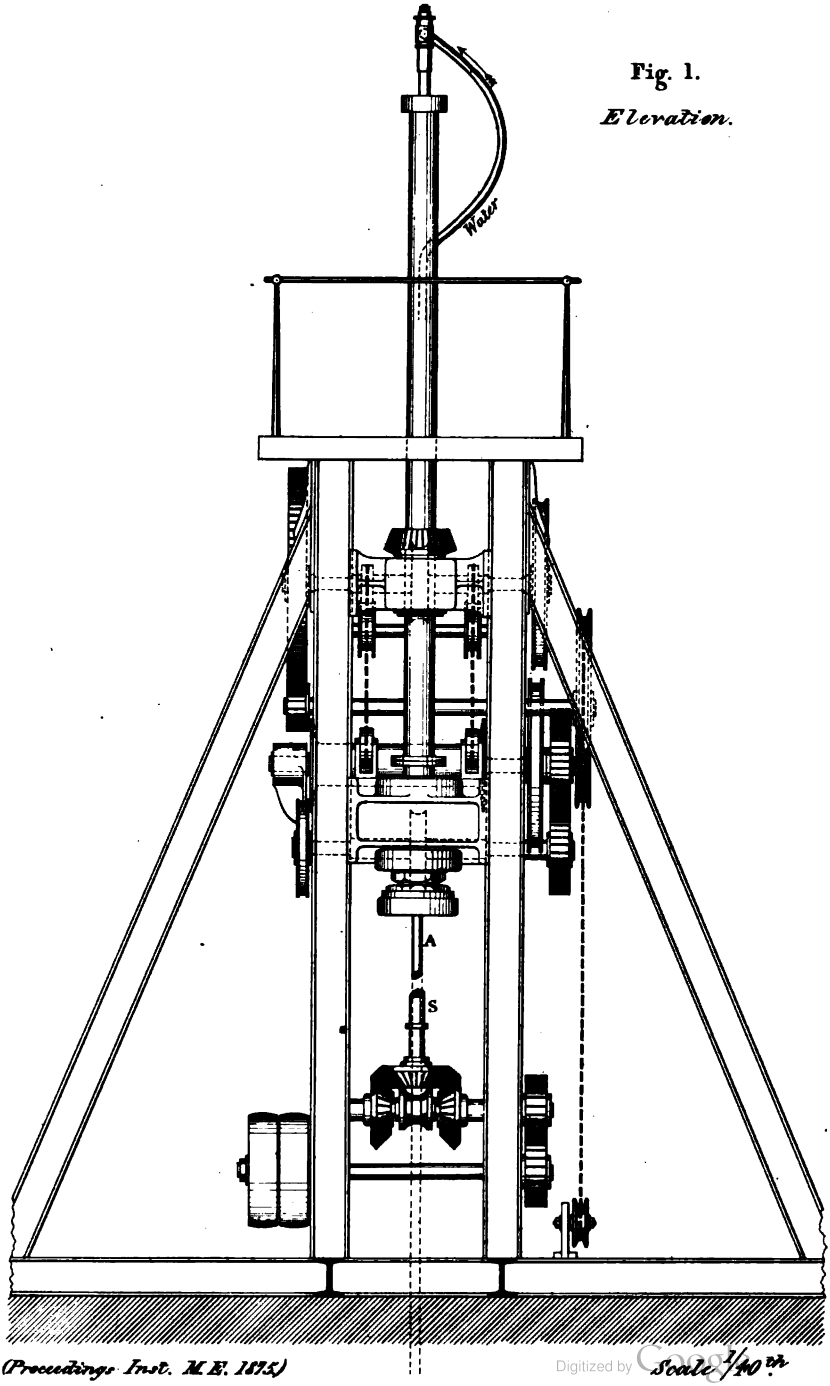
DIAMOND ROCK-DRILL. Plate 8.

Prospecting Machine.

Fig. 1.

Elevation.



(Proceedings Inst. M.E. 1875.) *Scale 1/40th.*

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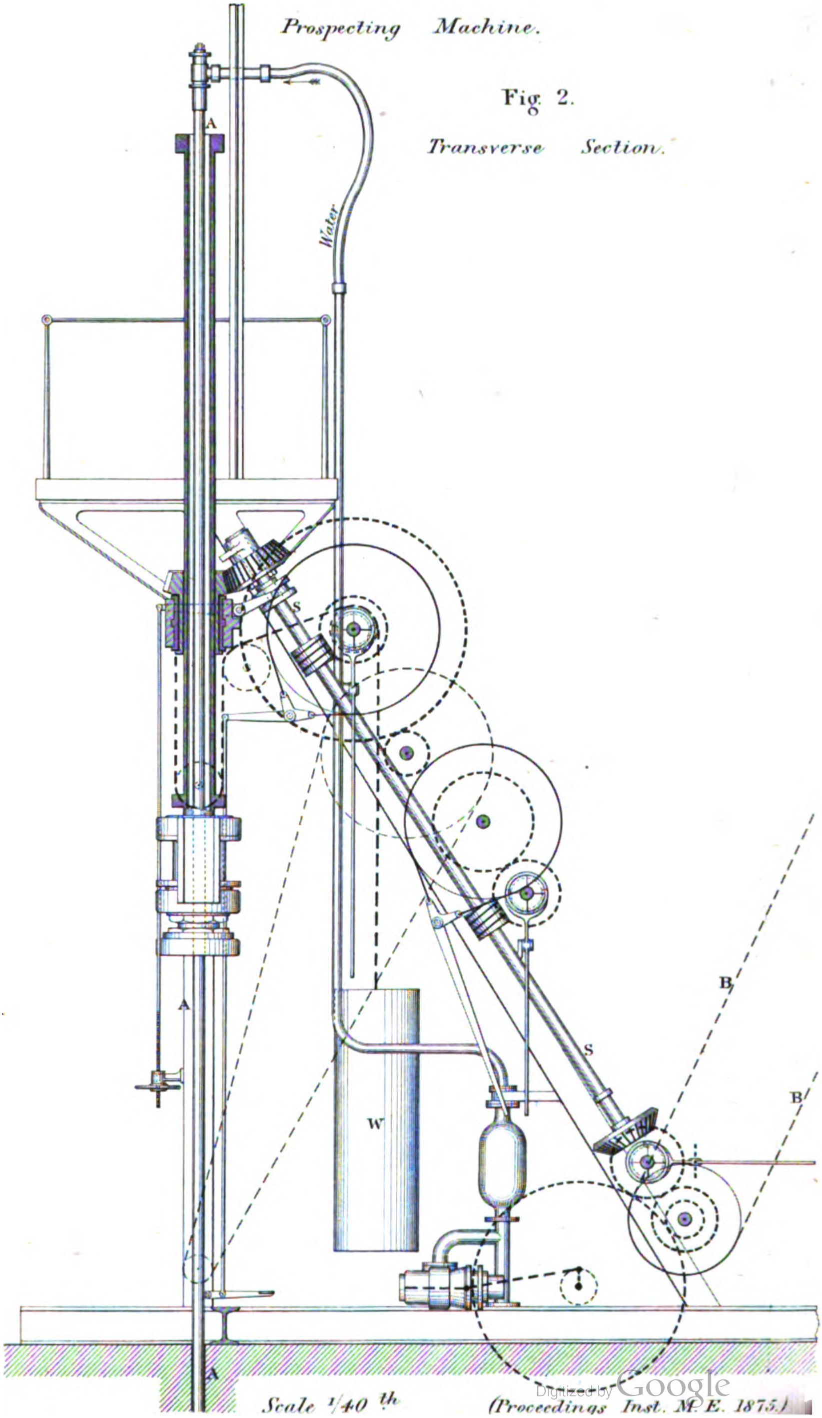
DIAMOND ROCK-DRILL. *Plate 9.*

Prospecting Machine.

Fig. 2.

Transverse Section.



Scale 1/40 th *(Proceedings Inst. M. E. 1875.)*

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DIAMOND ROCK - DRILL.

Tunnelling Machine.

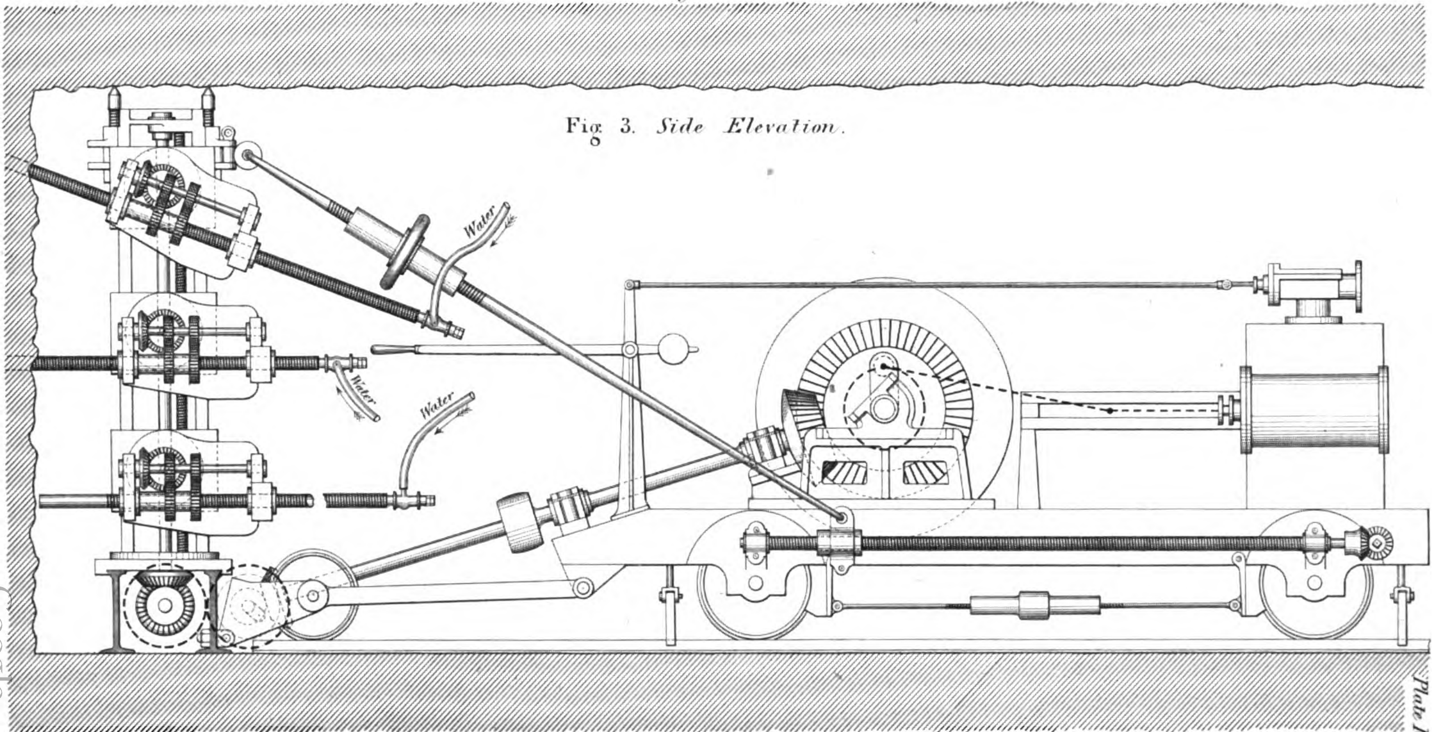

Fig. 3. *Side Elevation.*

Scale 1/24 th.

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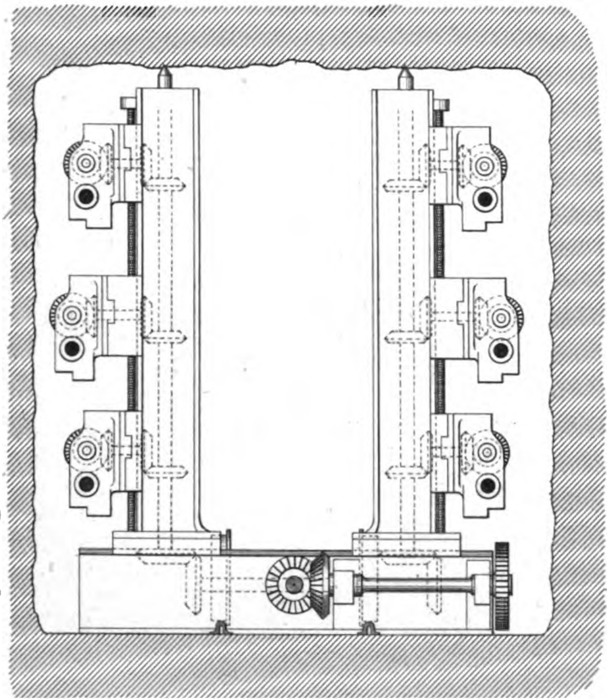
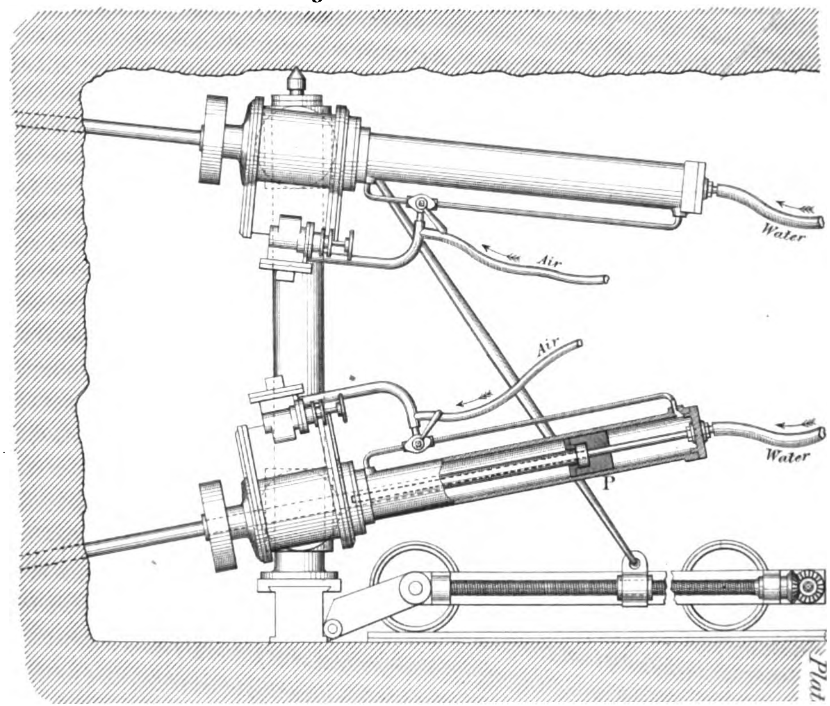
DIAMOND ROCK-DRILL. Plate II.

Tunnelling Machine.
Fig. 4. Transverse Section.



Improved Tunnelling Machine.
Fig. 5. Side Elevation.



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DIAMOND ROCK-DRILL.

Plate 12.

Shaft-Sinking Machine.

Fig. 6. *Elevation.*

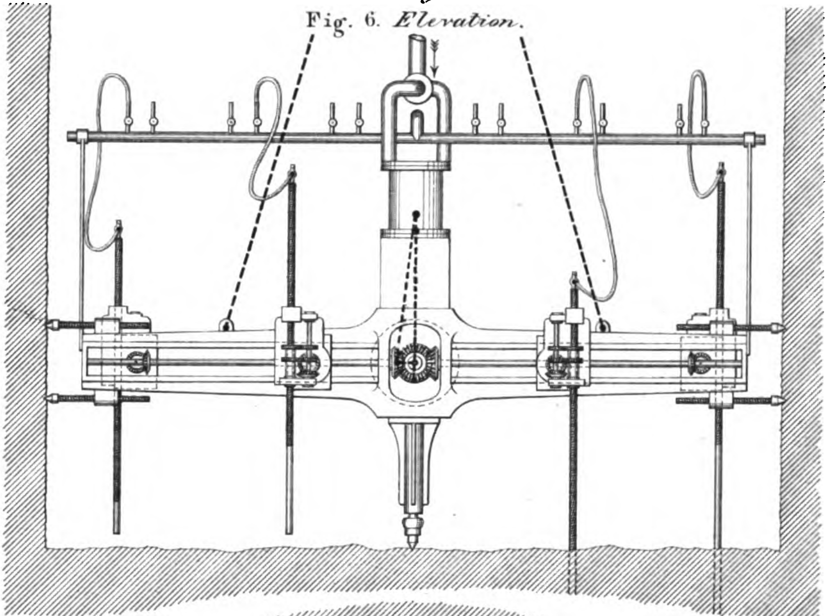
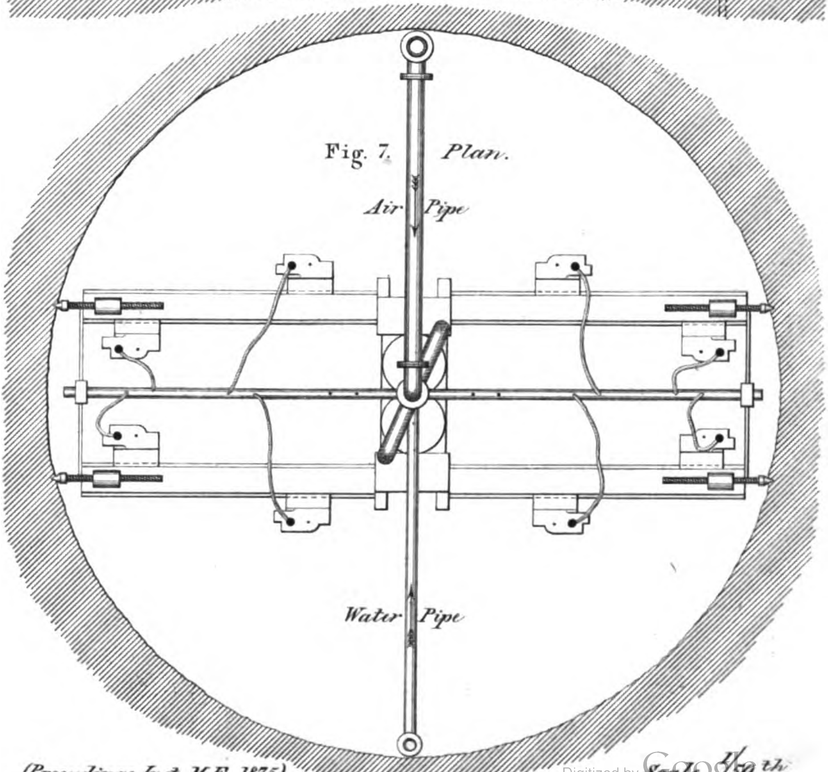


Fig. 7. *Plan.*



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Scale 1/50th.

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Fig. 8. *Improved Shaft-Sinking Machine.*

Scale 1/50th

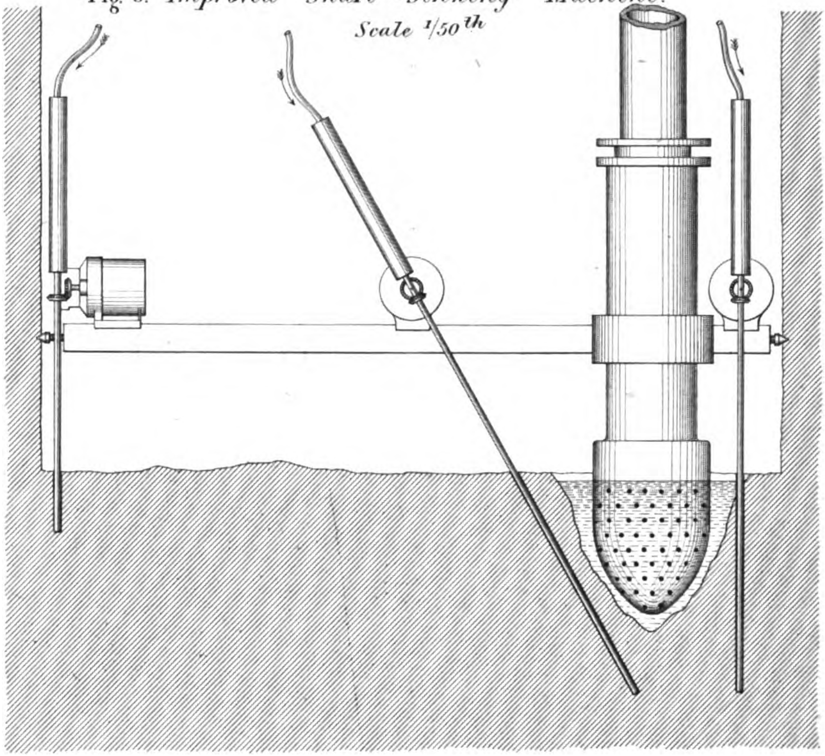
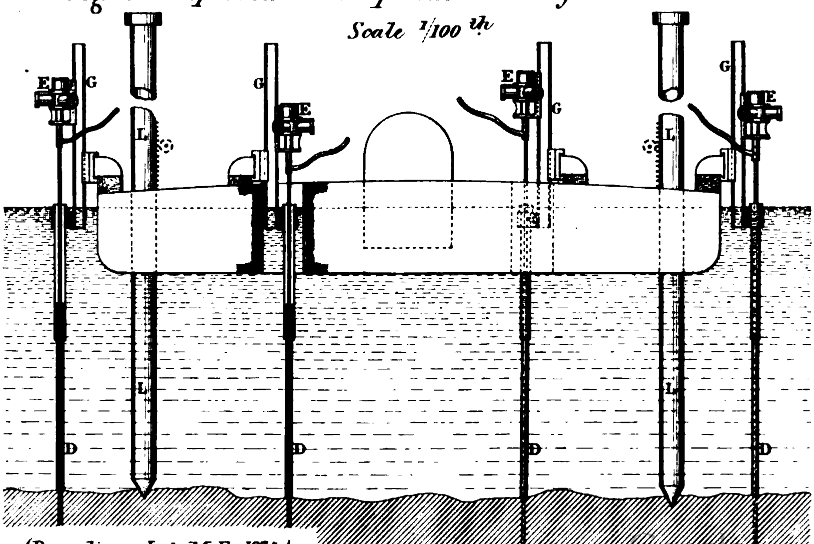


Fig. 9. *Improved Subaqueous Boring Machine.*

Scale 1/100th



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DIAMOND ROCK-DRILL. *Plate 14.*

Subaqueous Boring Machine.

Fig. 10. *Transverse Section.*

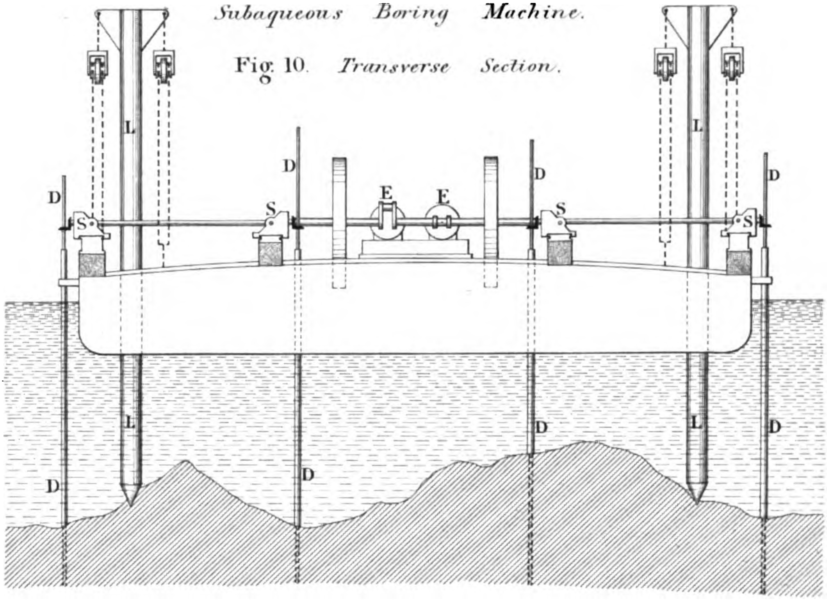

Fig. 11. *Plan of half length of barge.*

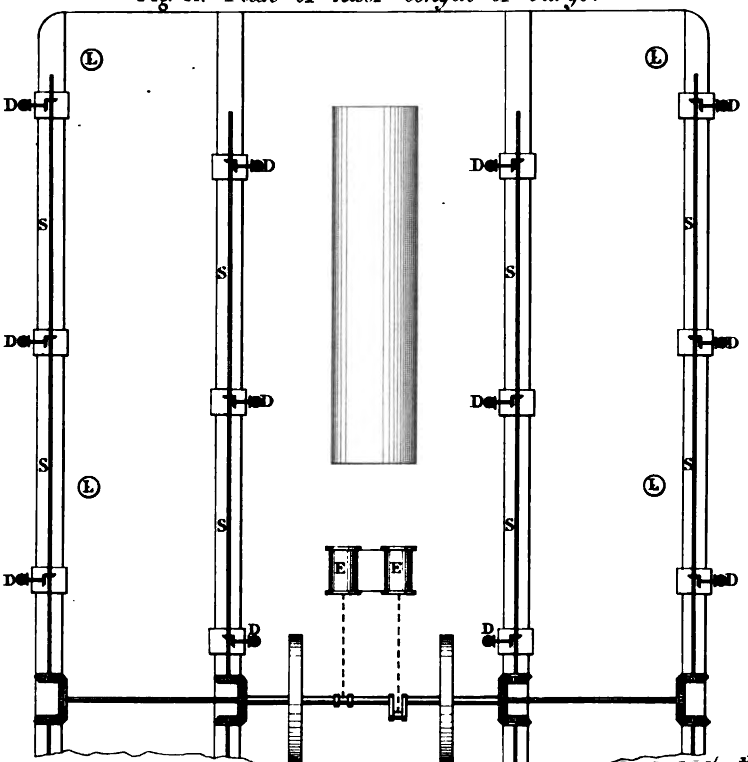

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Fig. 12. *Single Drill on Pile.*

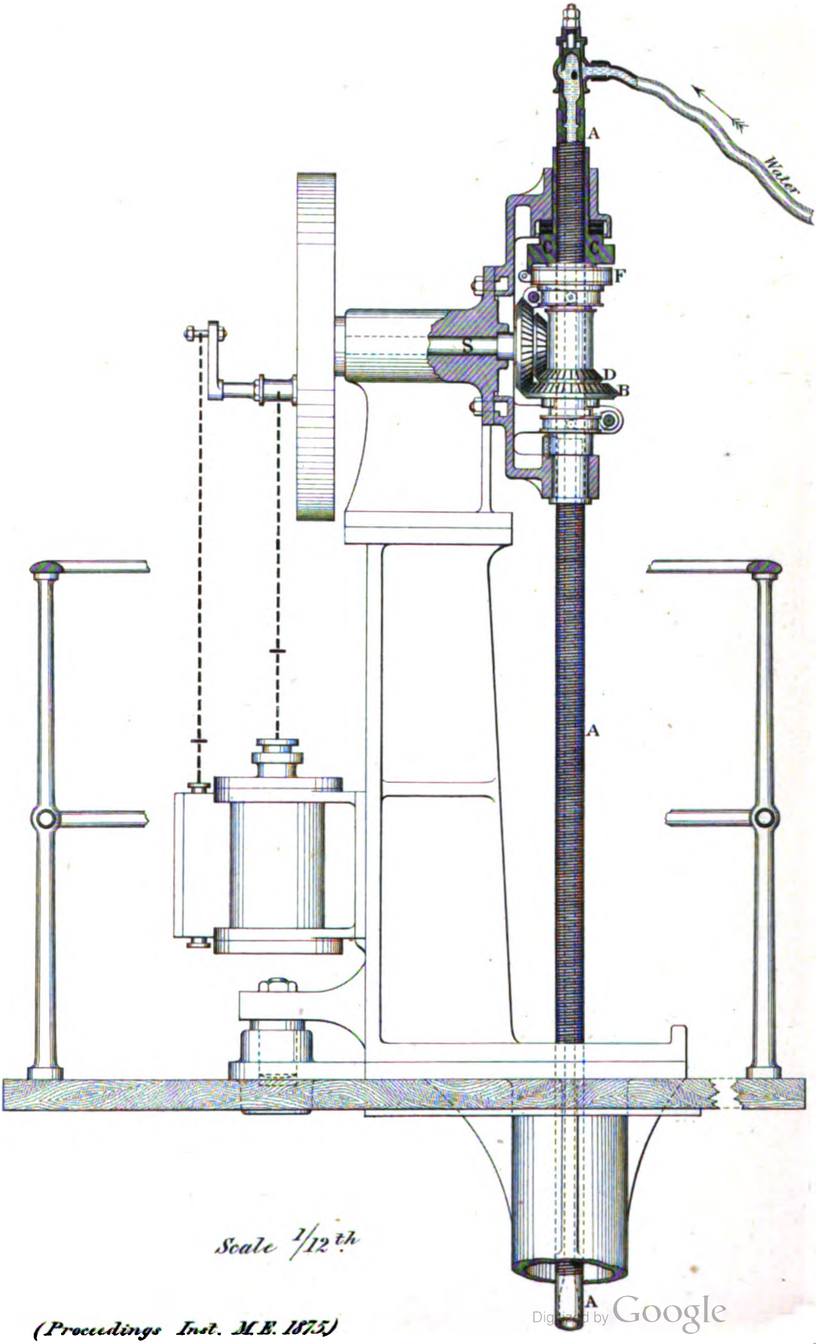

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Fig. 13.
Boring Rod.

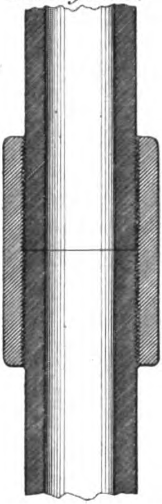
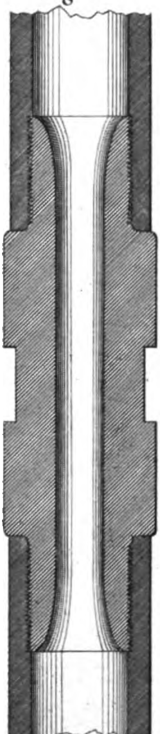
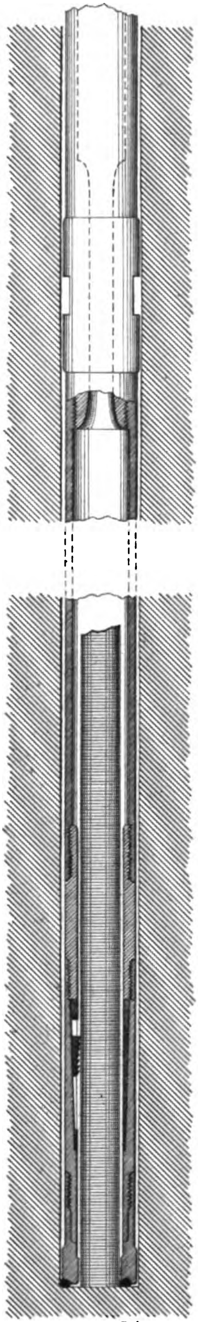


Fig. 14.



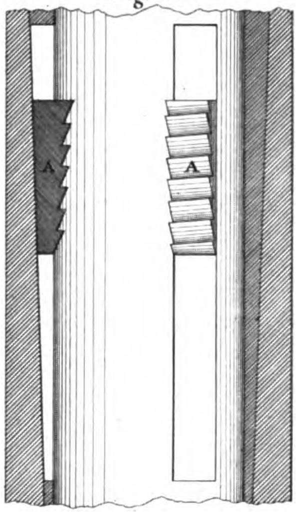
Scale 1/4th.

Fig. 15.
Core Tube.



Scale 1/8th.

Fig. 16.



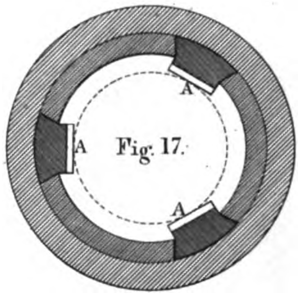
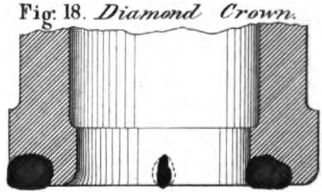


Fig. 17.

Fig. 18. *Diamond Crown.*



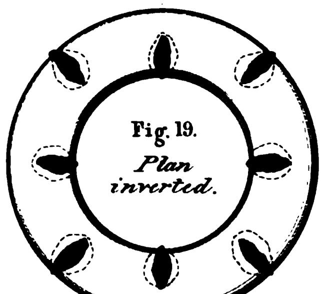


Fig. 19.
Plan inverted.

Scale half full size.

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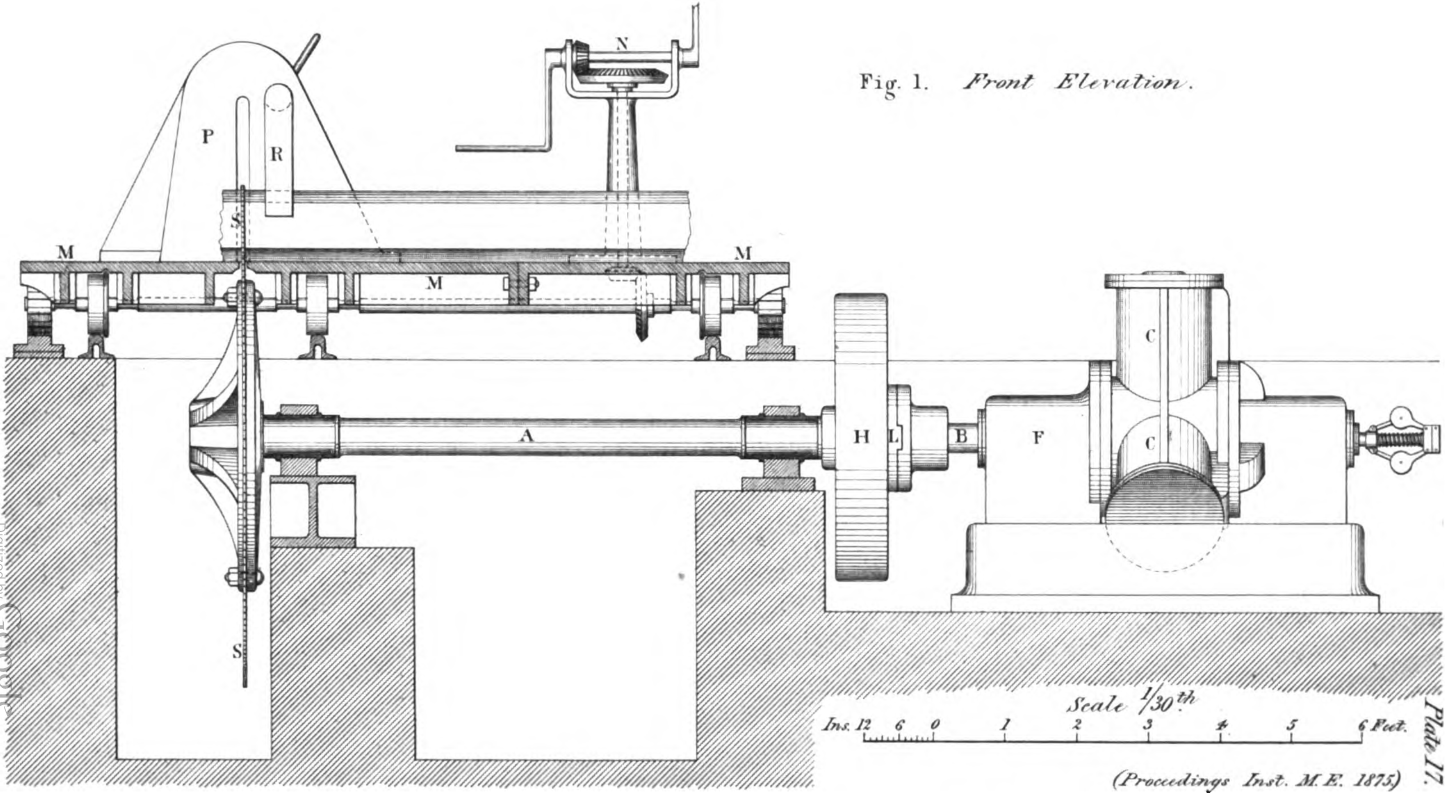
DIRECT-ACTING CIRCULAR SAW.

Fig. 1. *Front Elevation.*



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DIRECT - ACTING CIRCULAR SAW.

Fig. 2. *Transverse Section.*

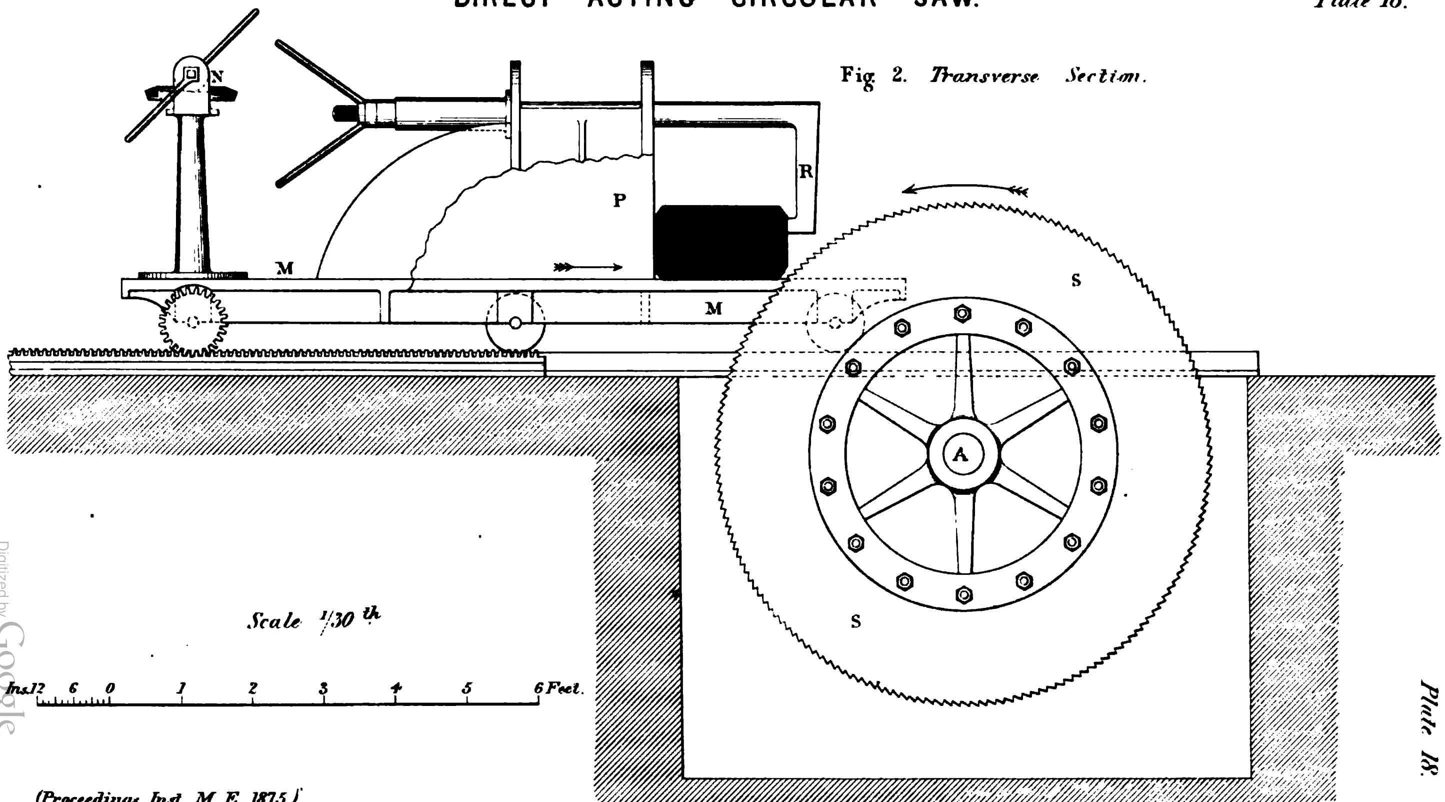

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Plate 18.

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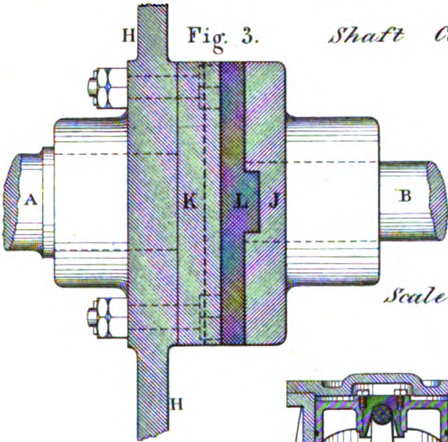
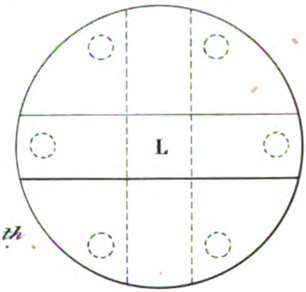
DIRECT-ACTING CIRCULAR SAW. *Plate 19.*

Fig. 3. *Shaft Coupling.* Fig. 4.





Scale 1/12th.

Fig. 5.
Transverse Section of Engine.

Scale 1/20th.

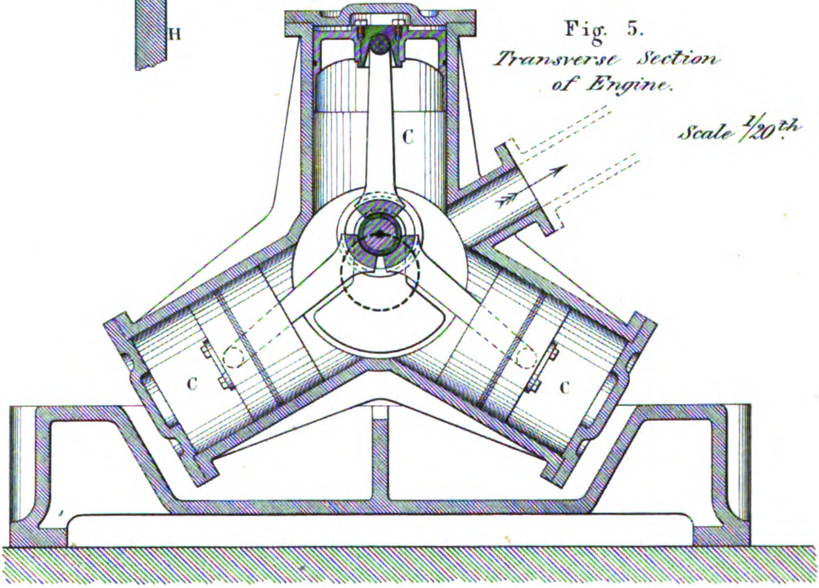
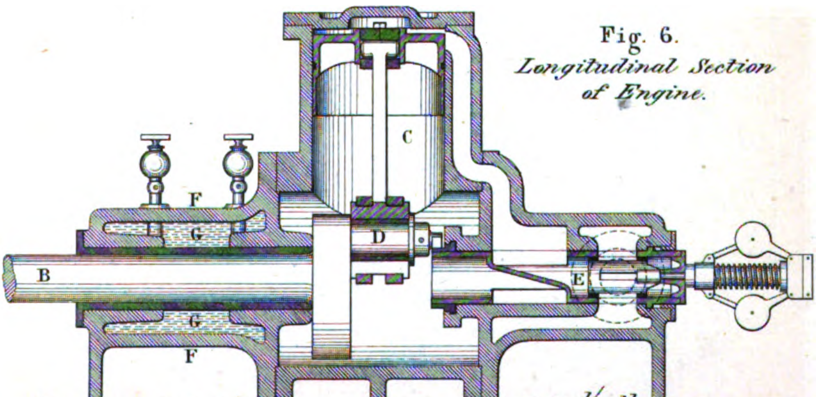


Fig. 6.
Longitudinal Section of Engine.



(Proceedings Inst. M.E. 1875) *Scale 1/20th.*

Ins. 12 6 0 1 2 3 4 5 Feet.

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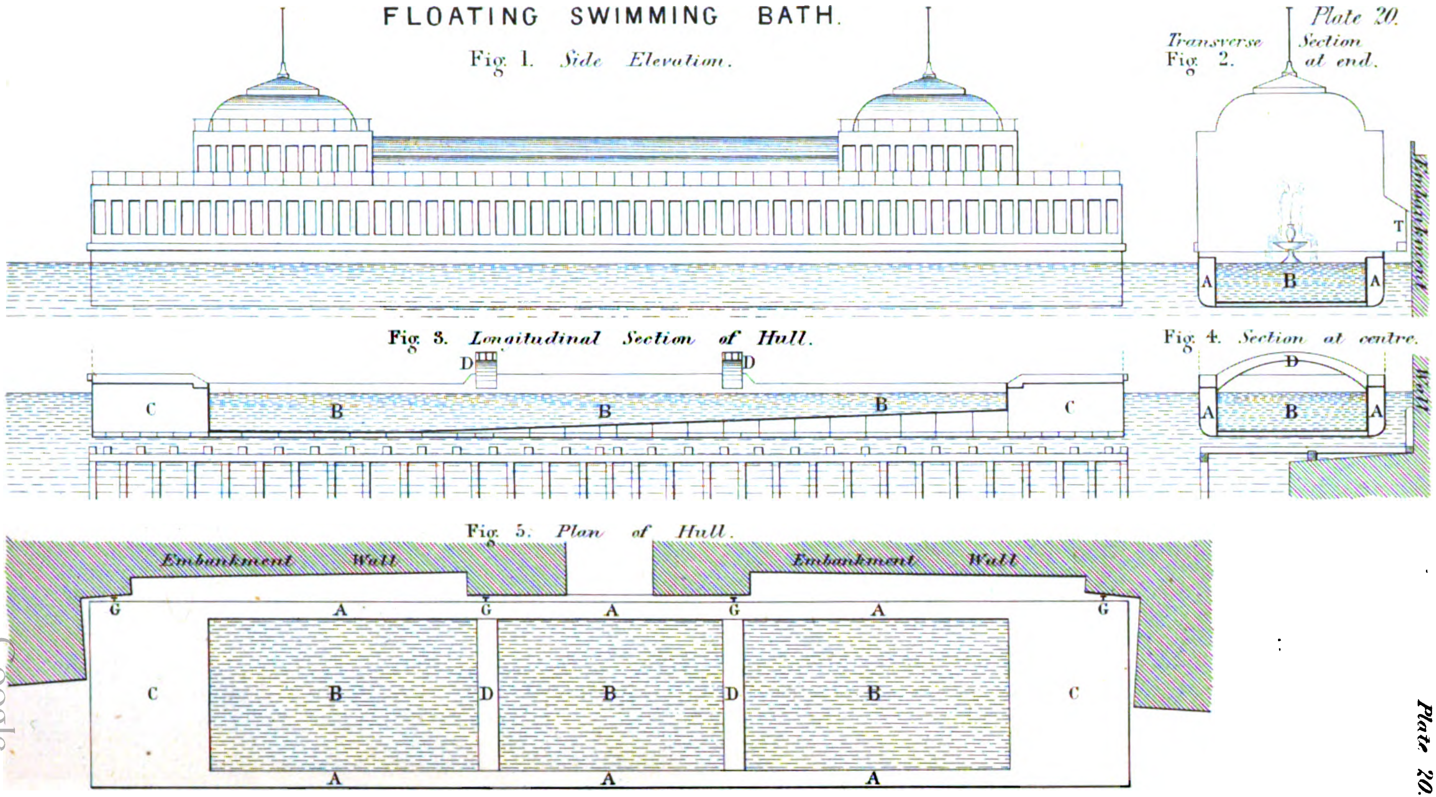
Plate 20.

FLOATING SWIMMING BATH.



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Scale 1/400 th

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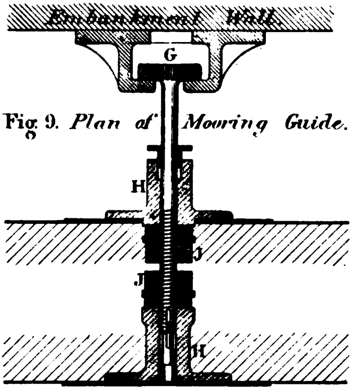


Fig. 9. *Plan of Mooring Guide.*

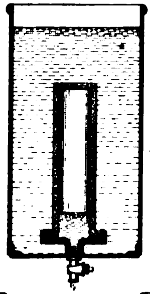


Fig. 10. *Stone Filter.*

Fig. 11.

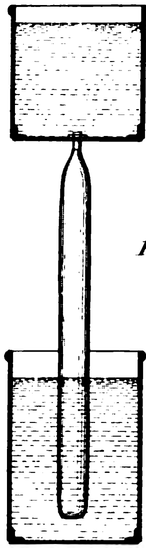
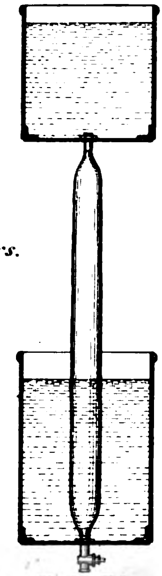


Fig. 12.



Bag Filters.

Fig. 13. *Stationary Cylindrical Cloth Filter.*

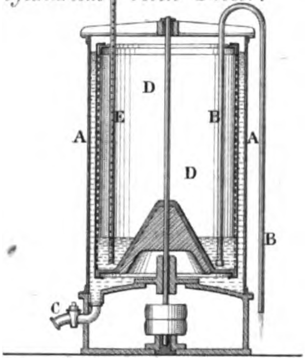


Fig. 14. *Centrifugal Cloth Filter.*

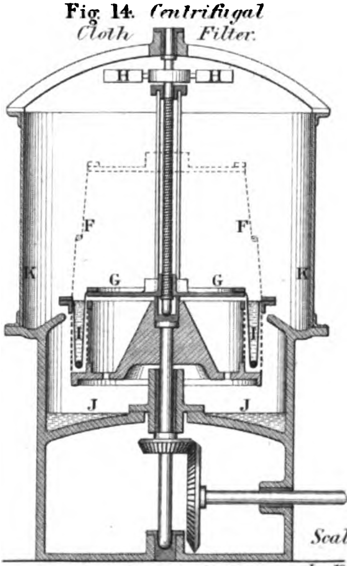
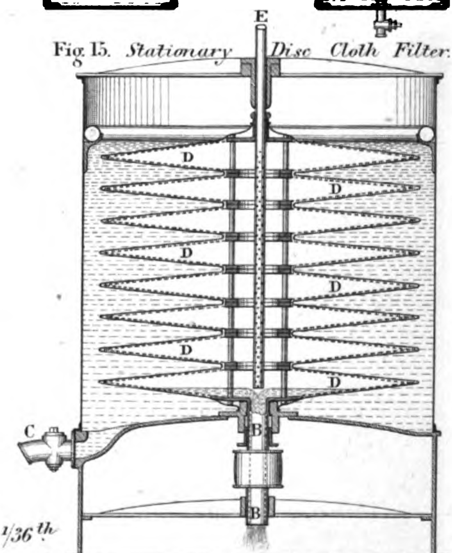


Fig. 15. *Stationary Disc Cloth Filter.*



Scale 1/36th.

Ins. 12 6 0 1 2 3 4 5 6 Feet.

(Proceedings Inst. M. E. 1875.)

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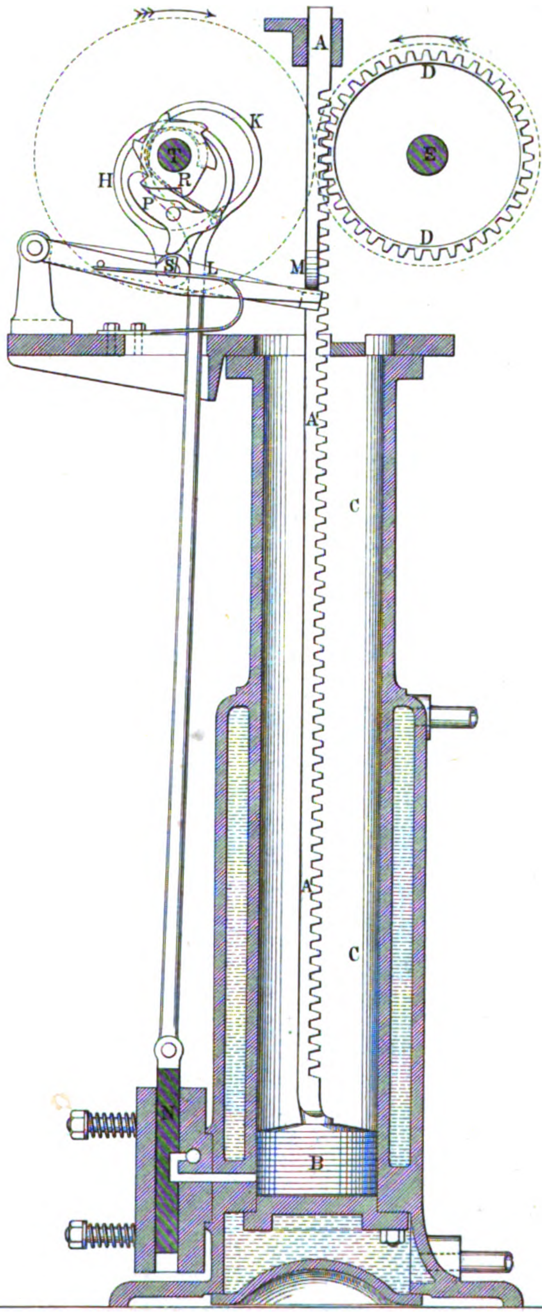
Fig. 1. *Vertical Section.* *Piston at bottom of stroke.*



(Proceedings Inst. M.E. 1875.) Scale 1/10th.

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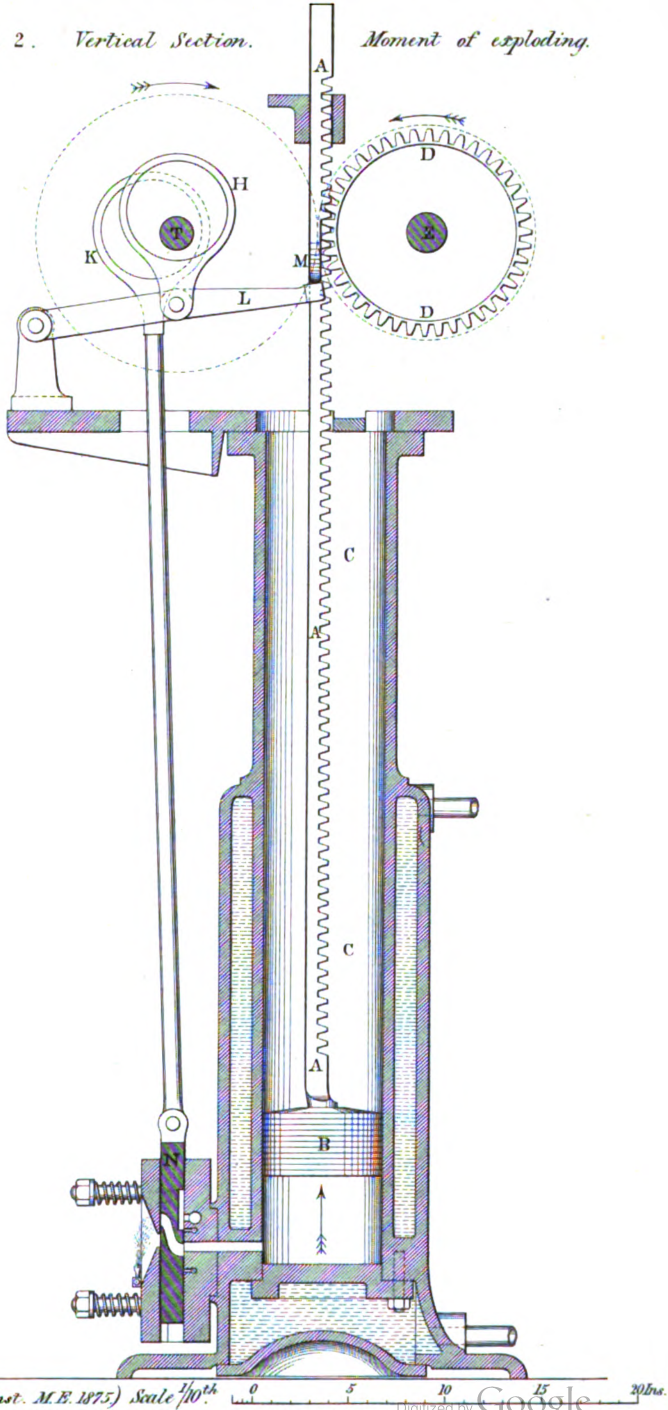
Fig. 2. Vertical Section. Moment of exploding.



(Proceedings Inst. M.E. 1875) Scale 1/10th

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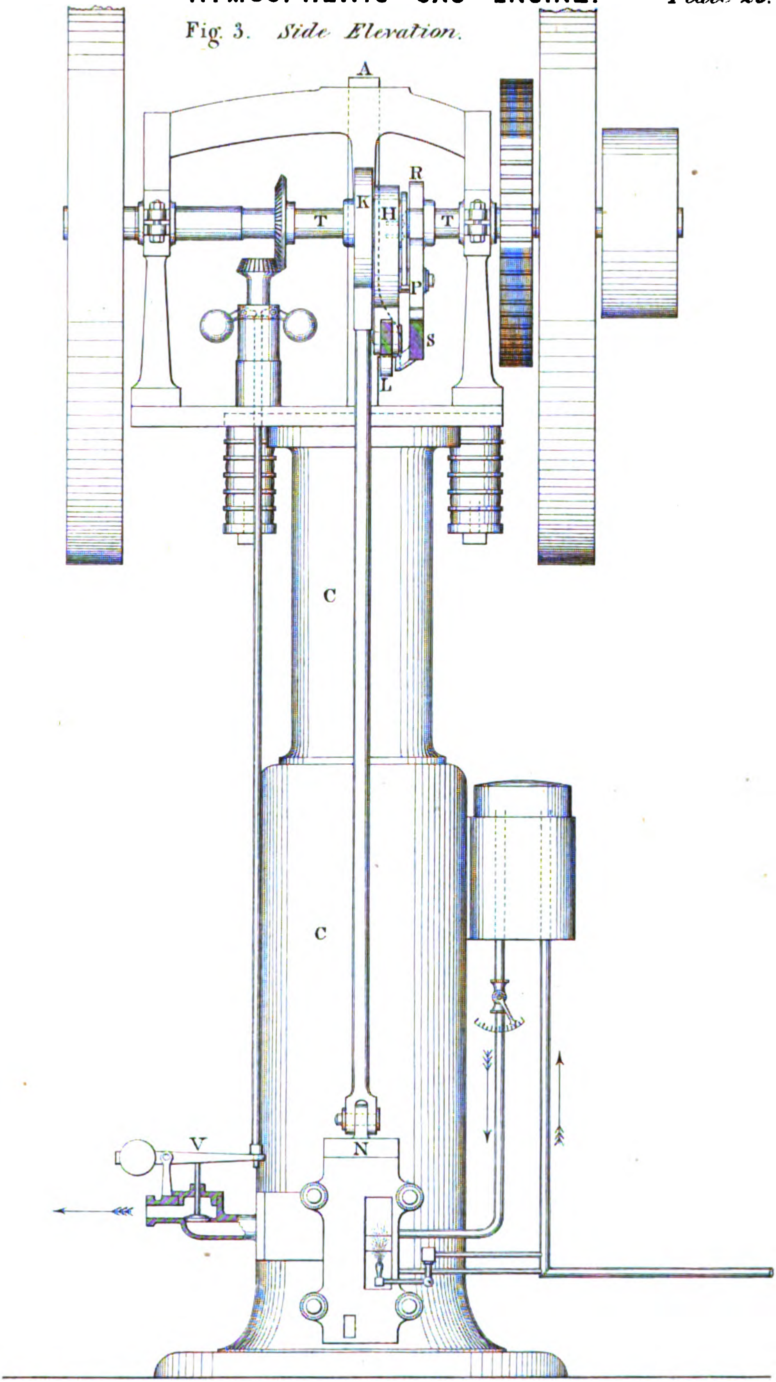
ATMOSPHERIC GAS ENGINE. *Plate 25.*

Fig. 3. *Side Elevation.*



(Proceedings Inst. M. E. 1875.) *Scale 1/10th* 0 5 10 15 20 Ins.

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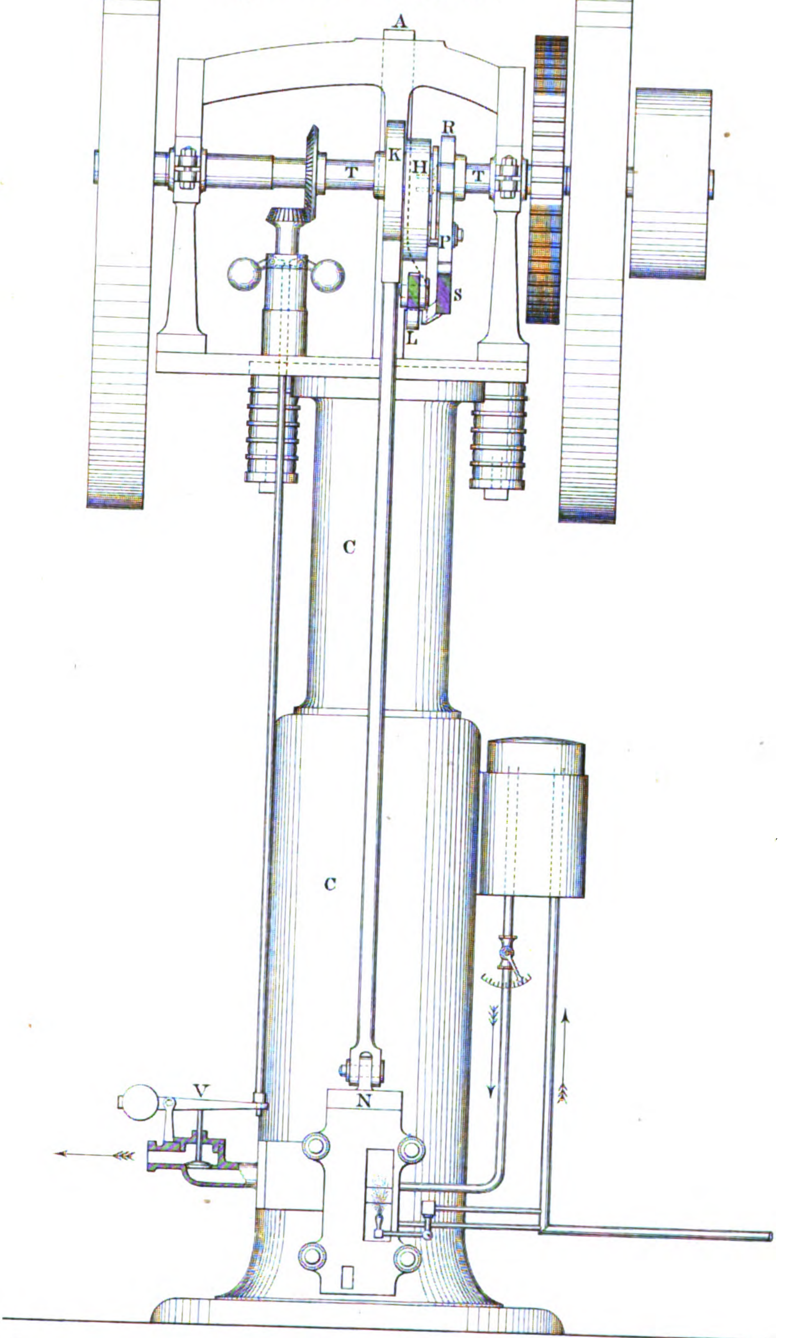
ATMOSPHERIC GAS ENGINE. Plate 25.

Fig. 3. *Side Elevation.*



(Proceedings Inst. M. E. 1875) Scale 1/10th

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Improved Governor Gear.

Fig. 4.

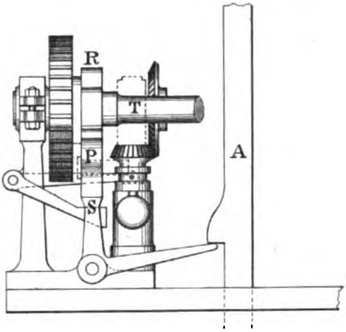
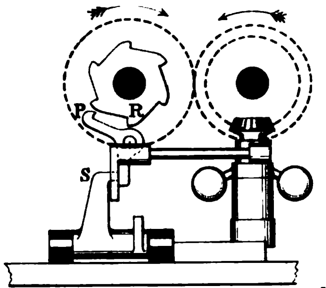


Fig. 5.



Scale 1/10 th

Frictional Driving Clutch.

Fig. 6. *Transverse Section.*

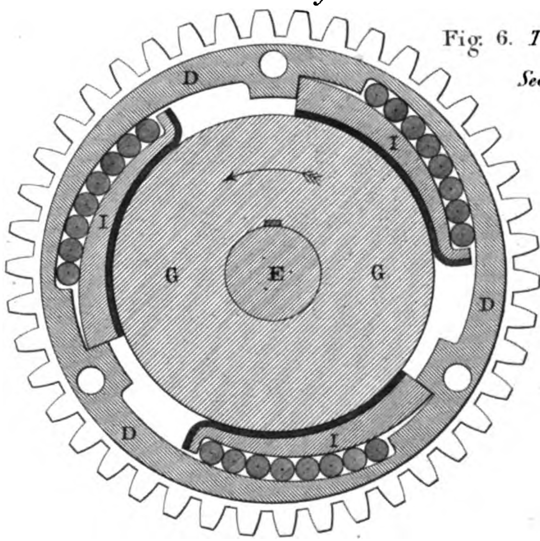
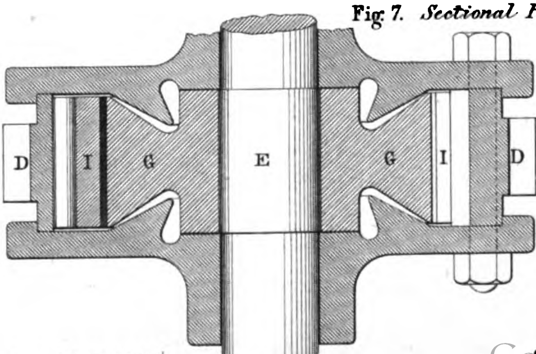


Fig. 7. *Sectional Plan.*



Scale 1/4 th

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Fig. 8. *Indicator Diagram, Otto and Langen Engine.*

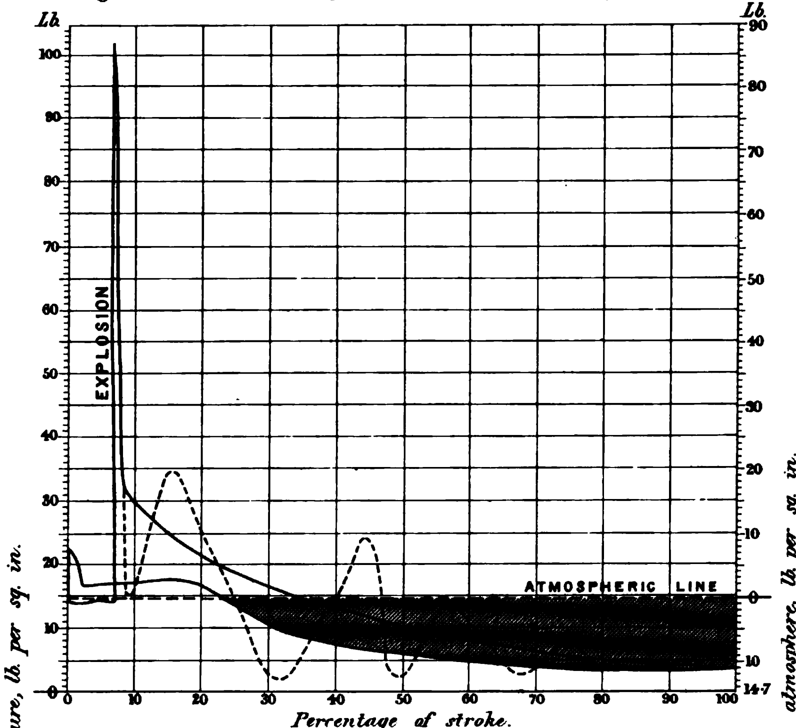
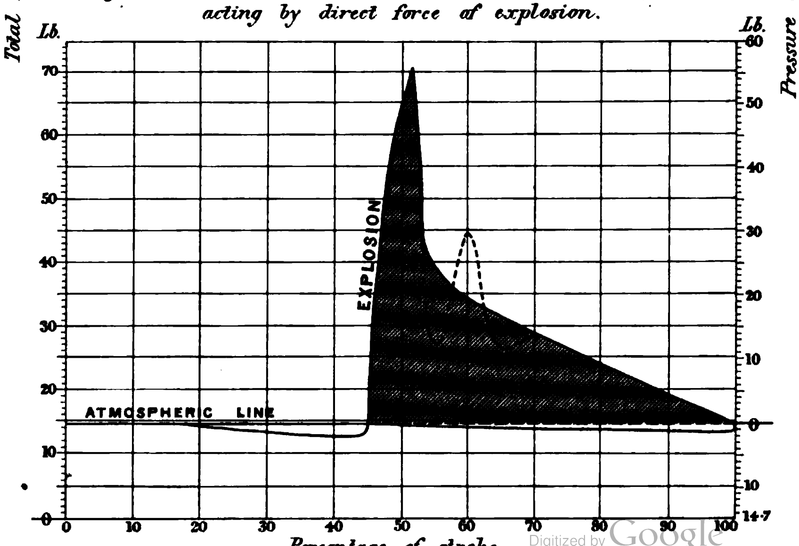


Fig. 9. *Indicator Diagram from Horizontal Gas Engine acting by direct force of explosion.*



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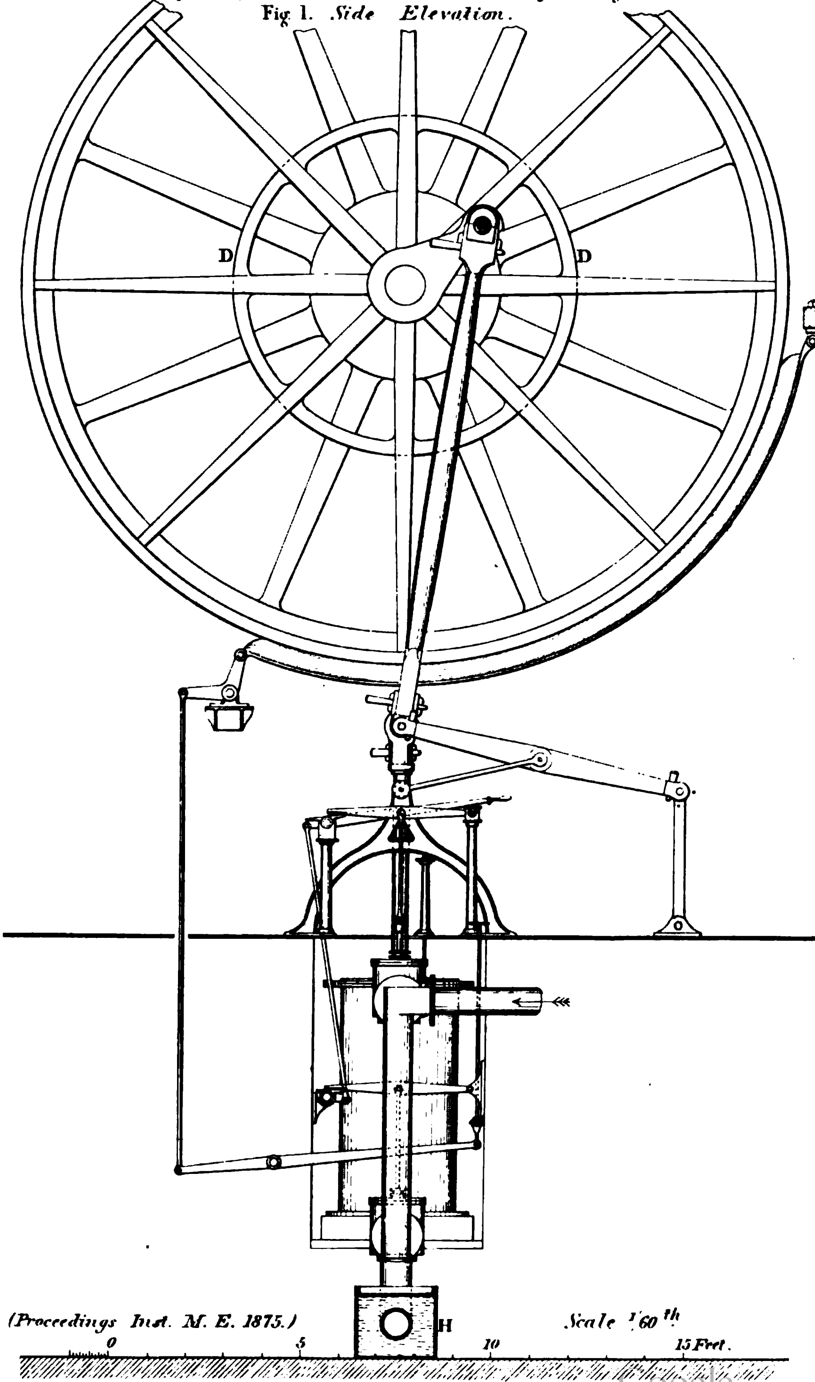
Single-Cylinder Vertical Winding Engine.

Fig. 1. Side Elevation.



(Proceedings Inst. M. E. 1875.)

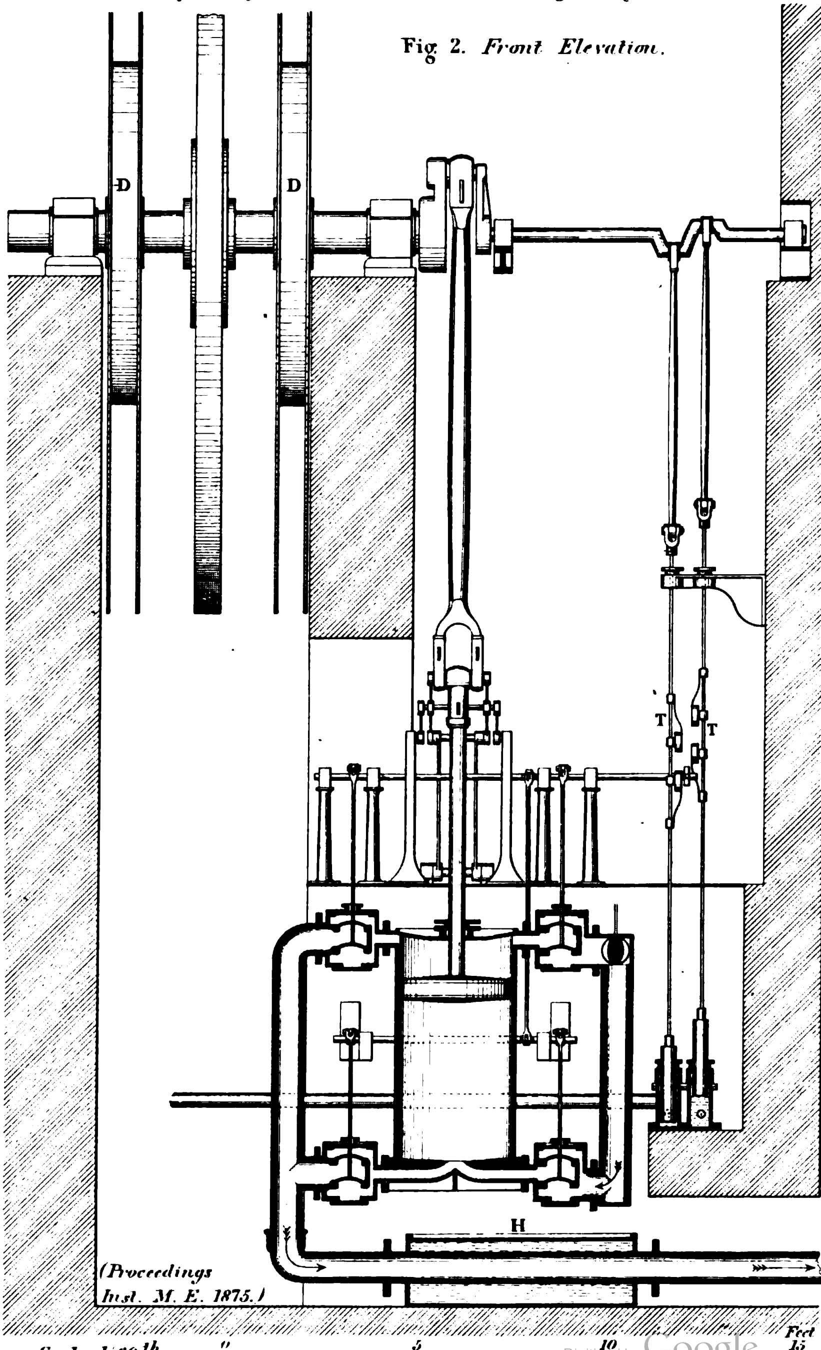
Scale 1/60th

Digitized by Google

Digitized by Google

Single-Cylinder Vertical Winding Engine.

Fig 2. *Front Elevation.*



Scale 1/60th

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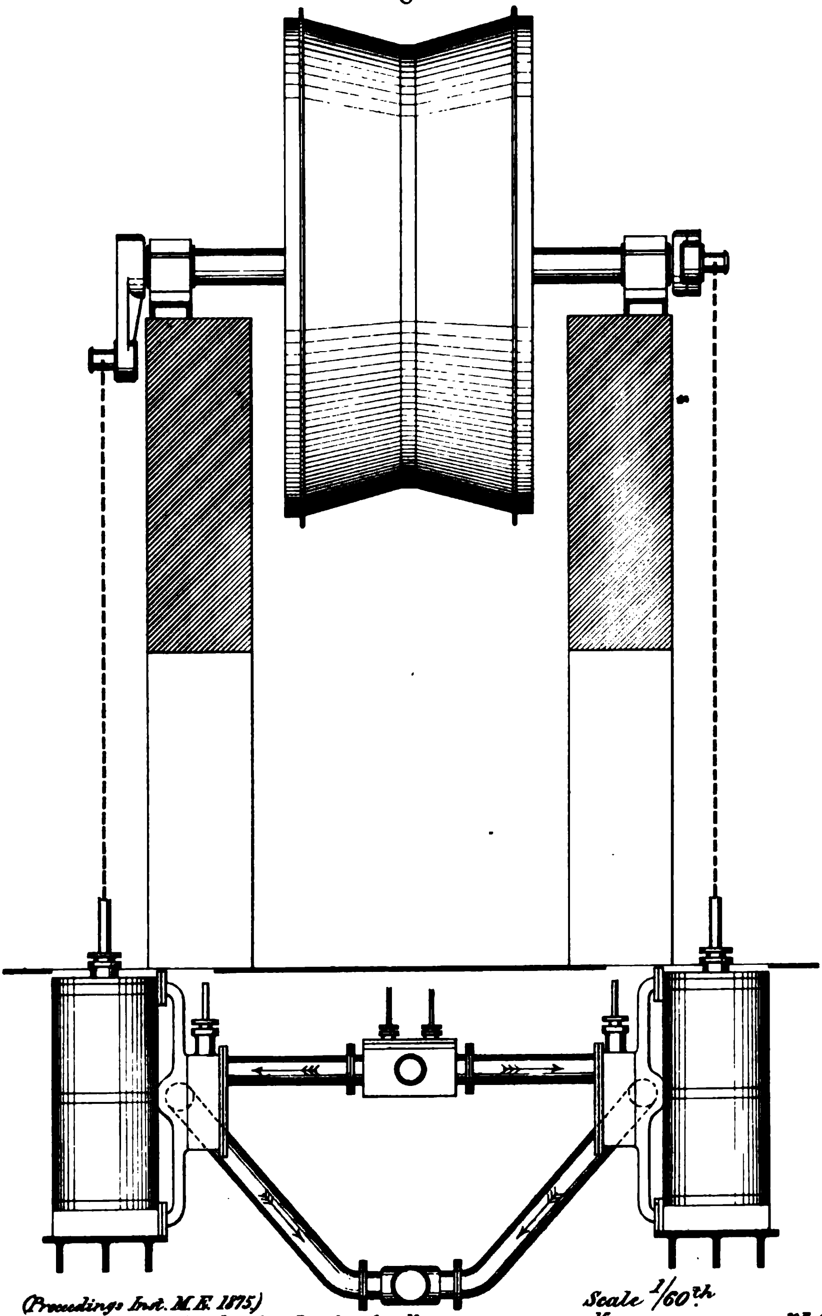
Coupled Pair of Vertical Winding Engines.

Fig. 3.



(Proceedings Inst. M.E. 1875)

Scale 1/60th

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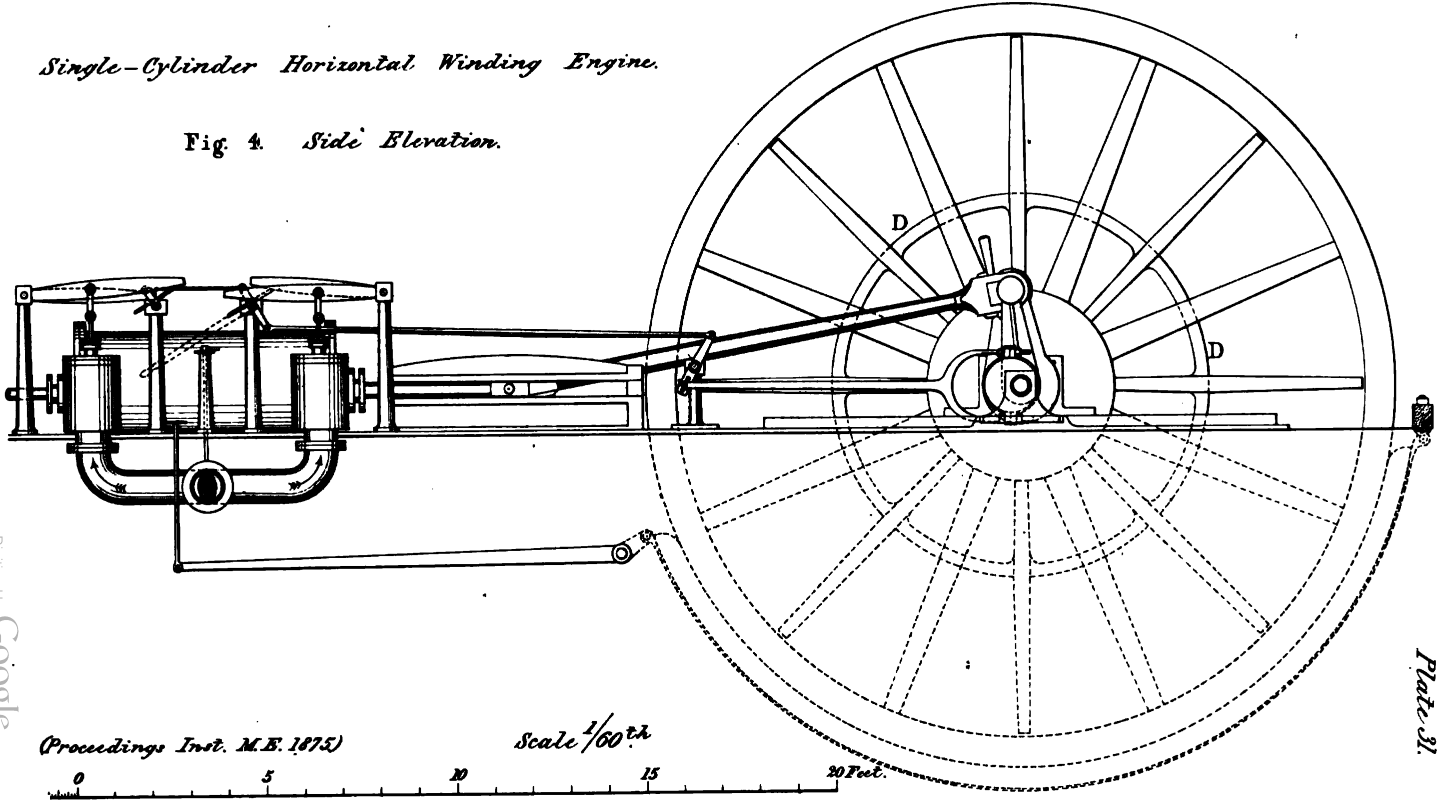
DIRECT-ACTING WINDING ENGINES.

Single-Cylinder Horizontal Winding Engine.

Fig. 4. *Side Elevation.*



Scale 1/60th

(Proceedings Inst. M.E. 1875)

Plate 31.

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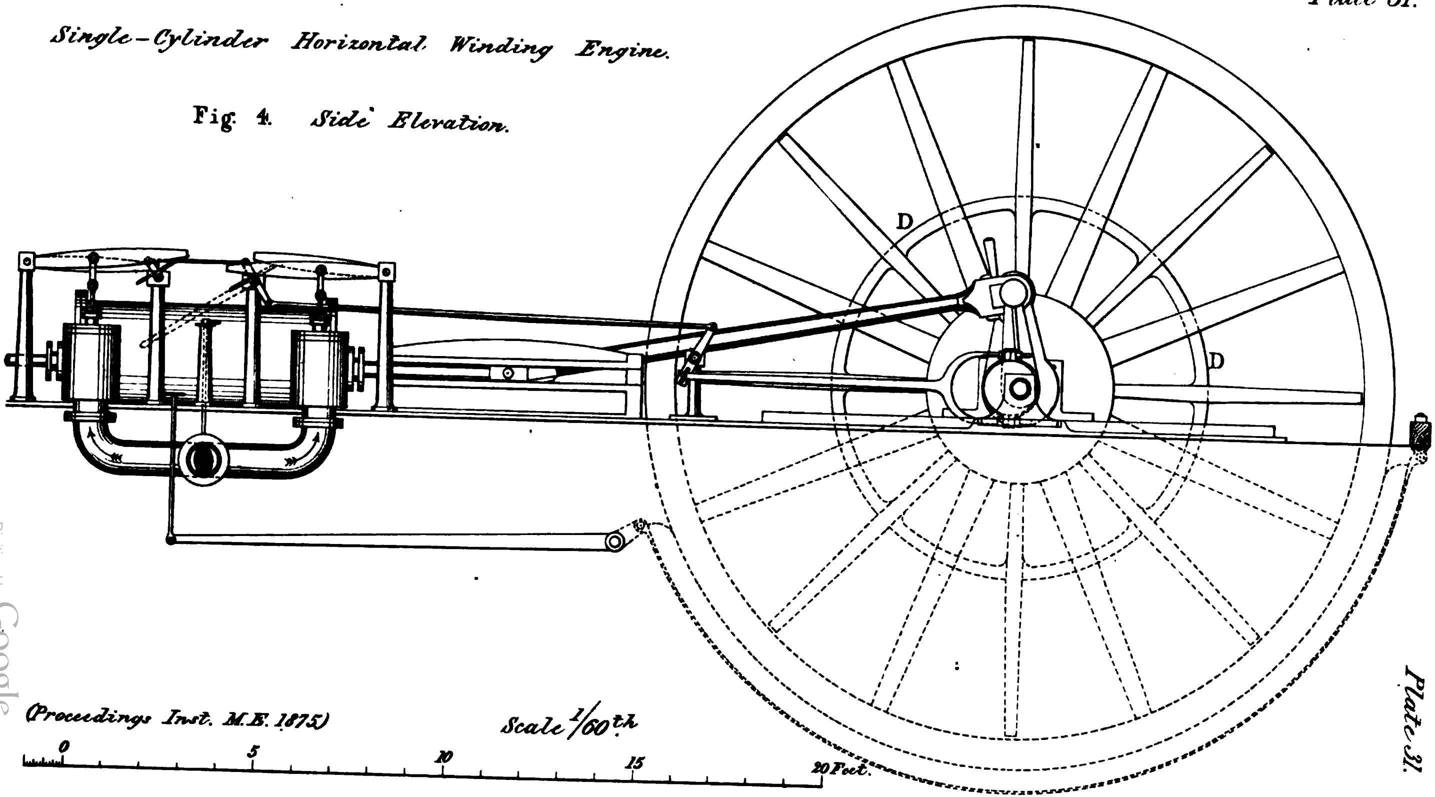
DIRECT-ACTING WINDING ENGINES.

Single-Cylinder Horizontal Winding Engine.

Fig. 4. *Side Elevation.*



(Proceedings Inst. M.E. 1875)

Scale 1/60th.

Plate 31.

Digitized by Google

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DIRECT-ACTING WINDING ENGINES.

Single-Cylinder Horizontal Winding Engine.

Fig. 6. *Transverse Section of Cylinder and Valves.*

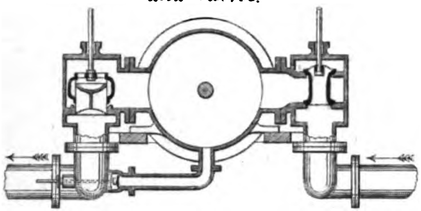

Fig. 5. *Plan.*

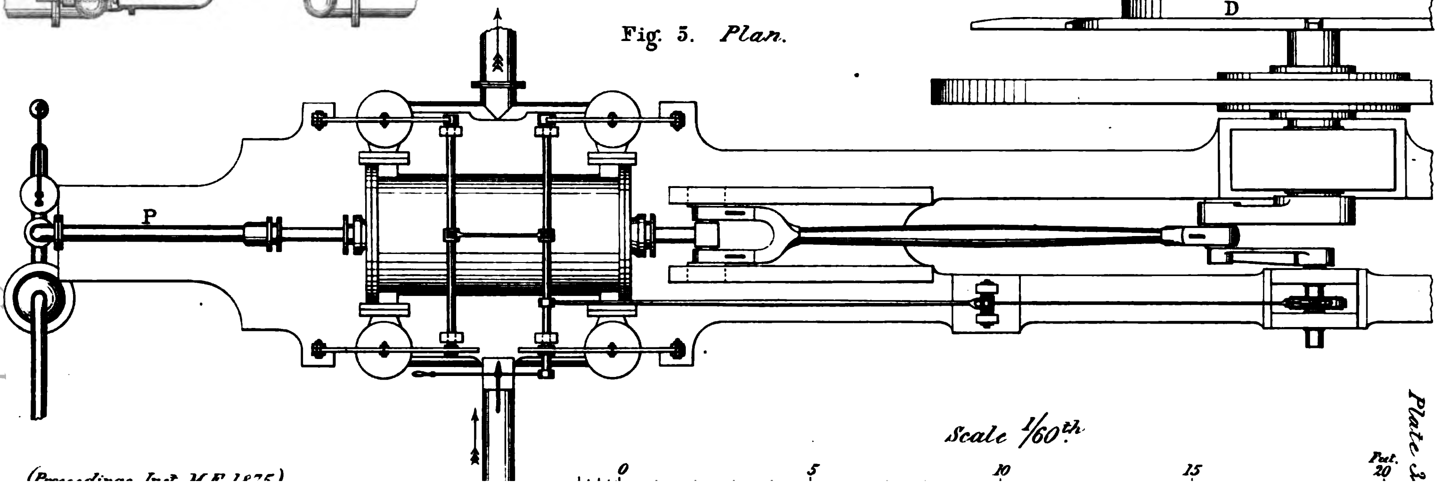

Plate 3

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DIRECT - ACTING WINDING ENGINES.

Coupled Pair of Horizontal Winding Engines with internal conical drum.

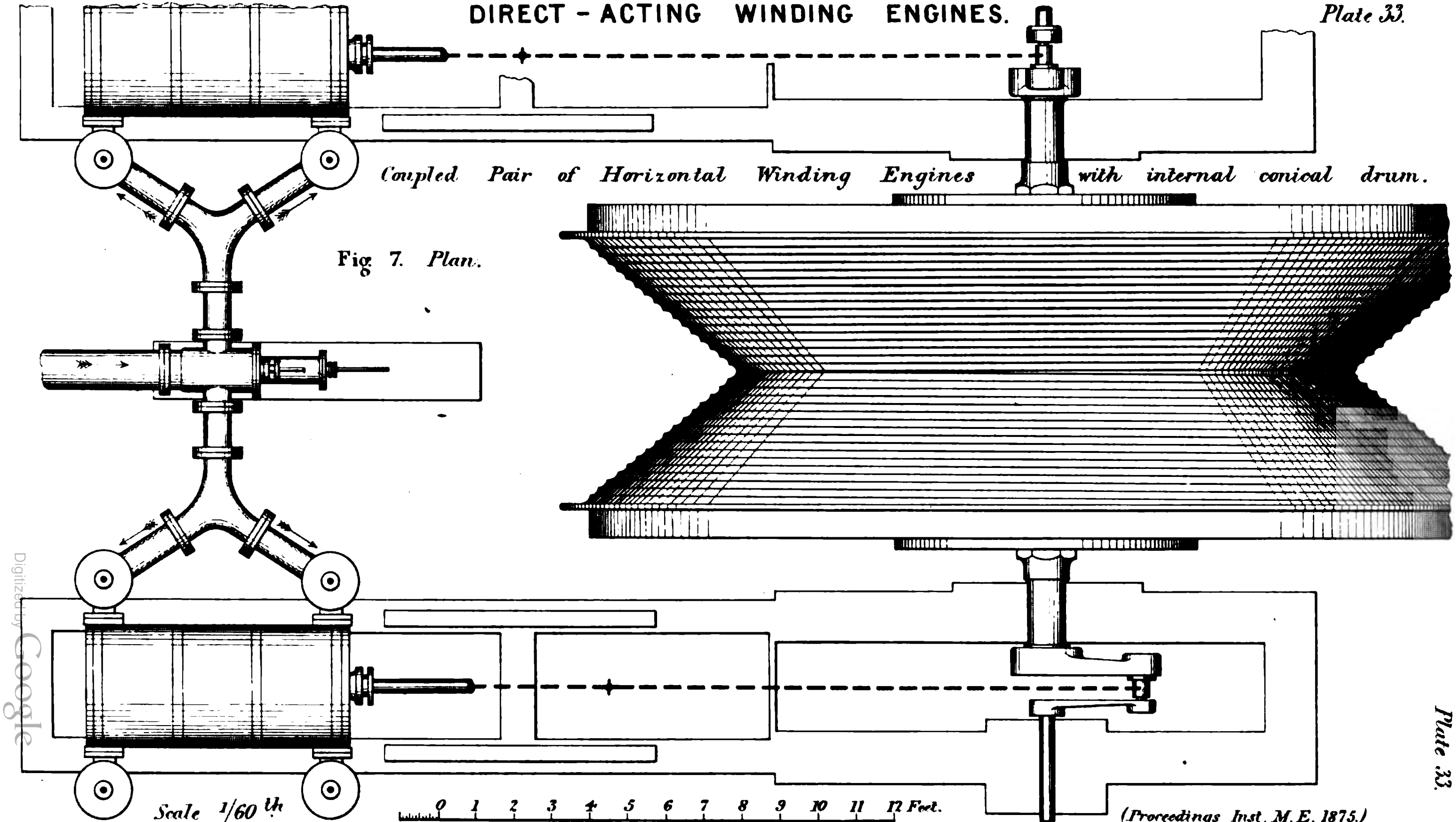

Fig. 7. *Plan.*

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Plate 33.

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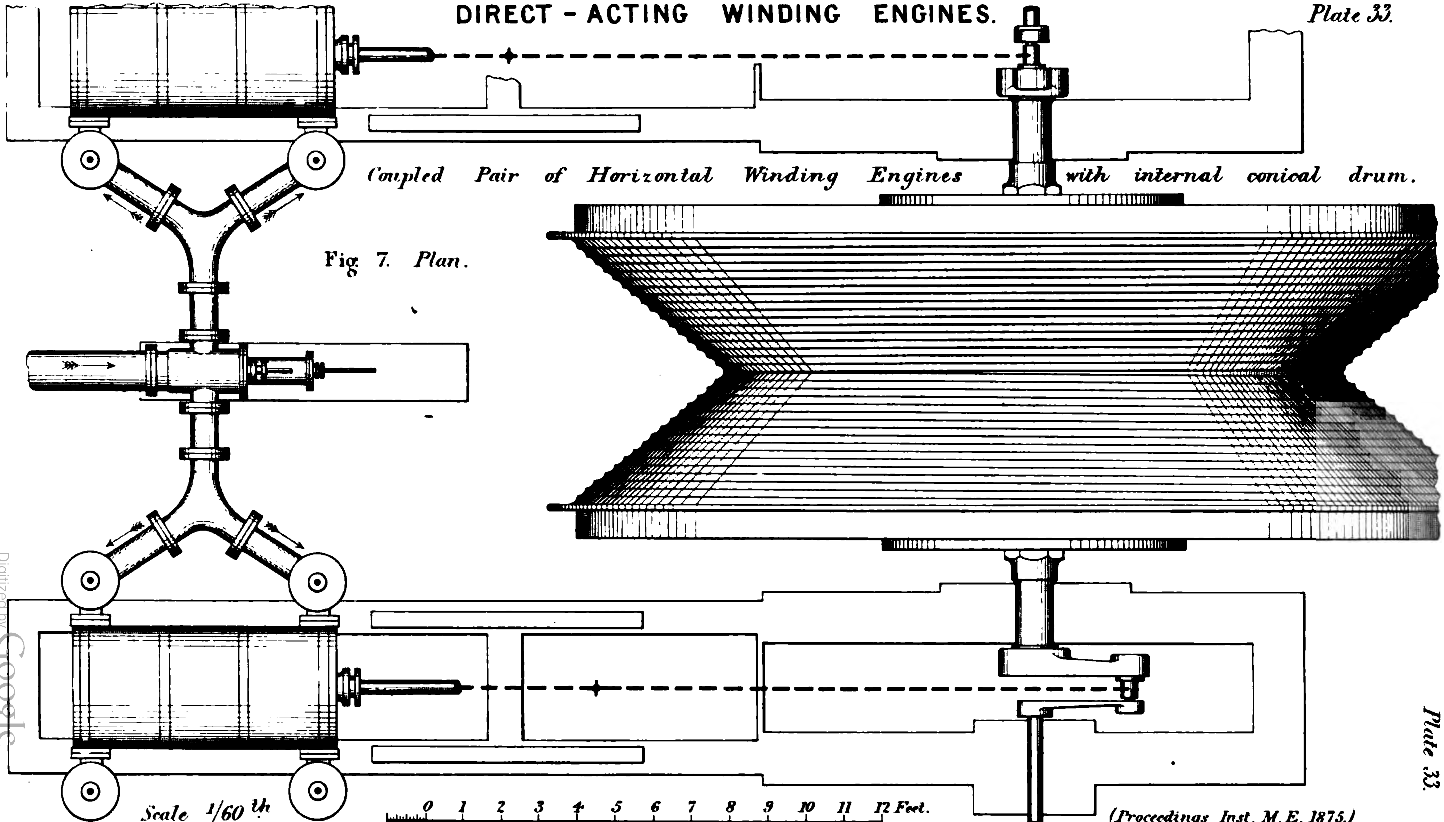
DIRECT - ACTING WINDING ENGINES. Plate 33.

Coupled Pair of Horizontal Winding Engines with internal conical drum.



(Proceedings Inst. M. E. 1875.)

Plate 33.

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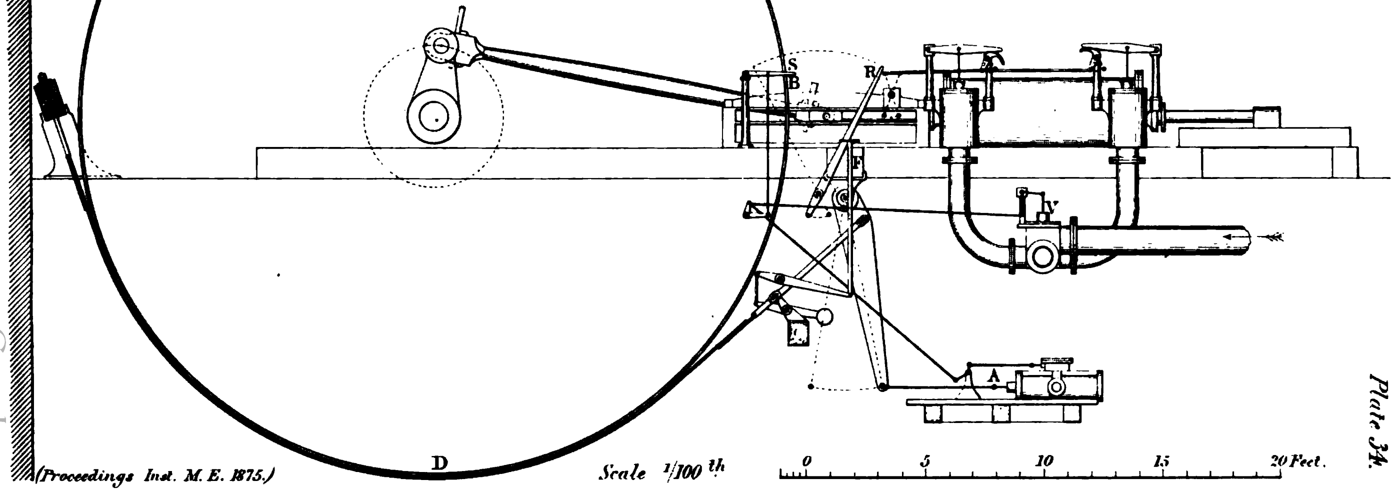
Plate 34.

DIRECT-ACTING WINDING ENGINES.

Coupled Pair of Horizontal Winding Engines with external conical drum.

Fig. 8. *Side Elevation.*



Scale 1/100 th

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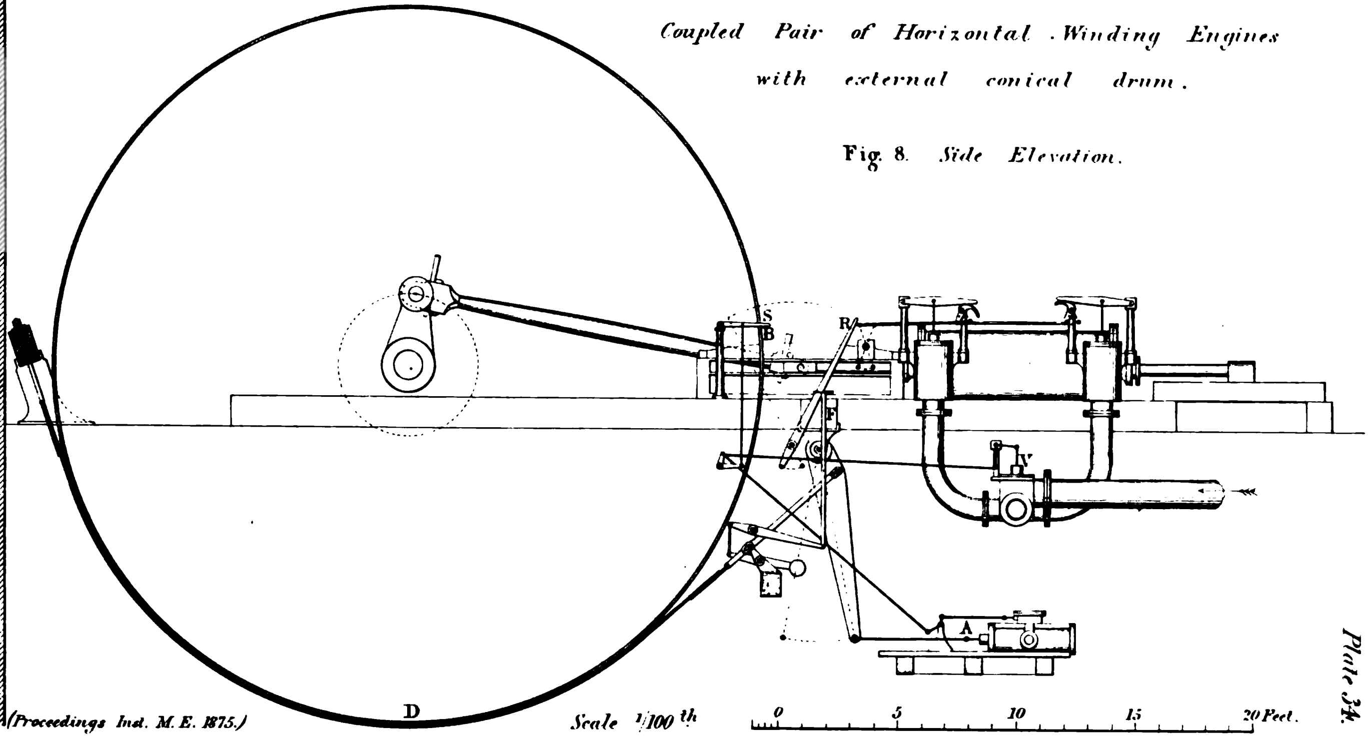
DIRECT-ACTING WINDING ENGINES.

Coupled Pair of Horizontal Winding Engines with external conical drum.

Fig. 8. *Side Elevation.*



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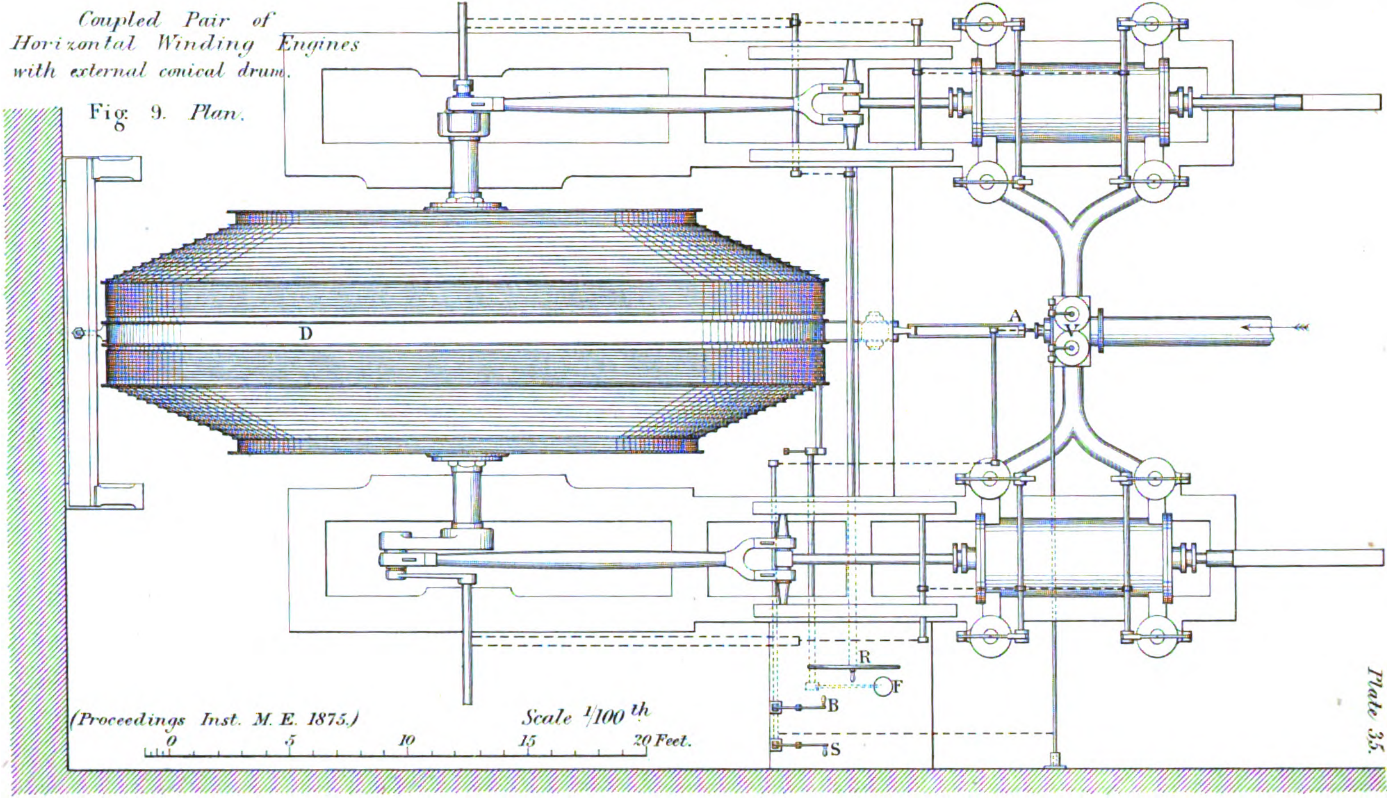
DIRECT-ACTING WINDING ENGINES.

Coupled Pair of Horizontal Winding Engines with external conical drum.

Fig. 9. *Plan.*



(Proceedings Inst. M. E. 1875.)

Plate 35.

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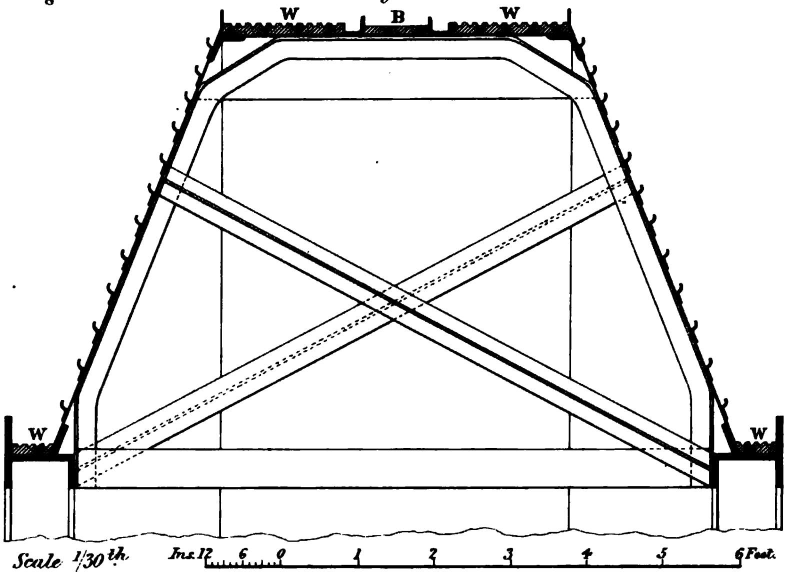
Fig. 10. *Section of Conical Winding Drum, diameters* 19 *ft.* *and* 30½ *ft.*



Scale 1/30th.

Diagrams of Conical Winding Drums.

Fig. 11. *Diameters* 13 *ft.* *and* 20 *ft.*

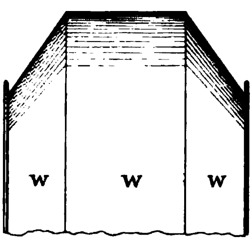


Fig. 12. *Diameters* 19 *ft.* *and* 30 *ft.*

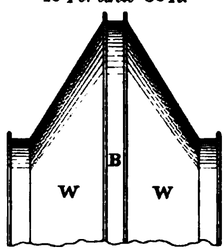
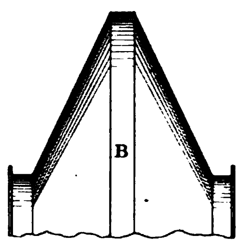


Fig. 13. *Diameters* 17½ *ft.* *and* 31½ *ft.*



W *wood lagging grooved for ropes.* B *break surface.*

Fig. 14. *Diameters* 16 *ft.* *and* 27 *ft.*

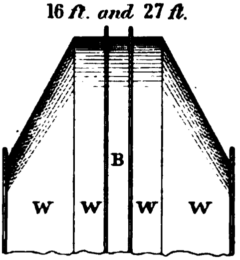


Fig. 15. *Diameters* 20½ *ft.* *and* 30 *ft.*

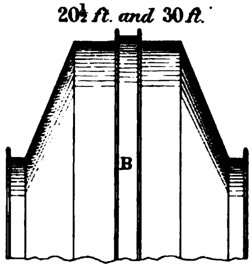
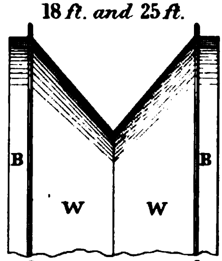


Fig. 16. *Diameters* 18 *ft.* *and* 25 *ft.*



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Other modes of Counterbalancing.

Fig. 17. *Lever or Crank Counterbalance.*

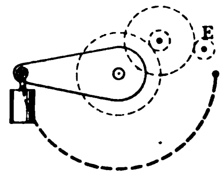


Fig. 18. *Pendulum Counterbalance.*

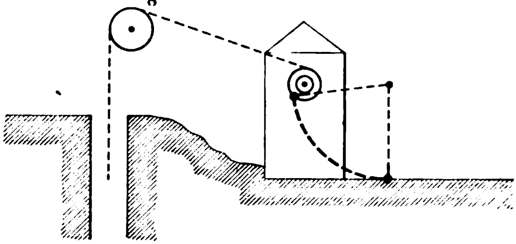


Fig. 19. *Inclined-Plane Counterbalance.*

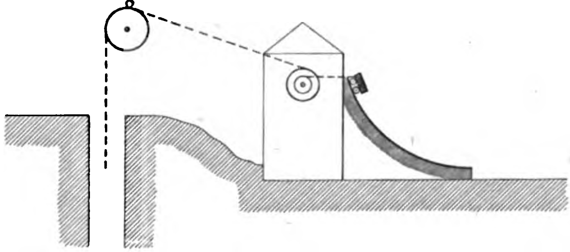
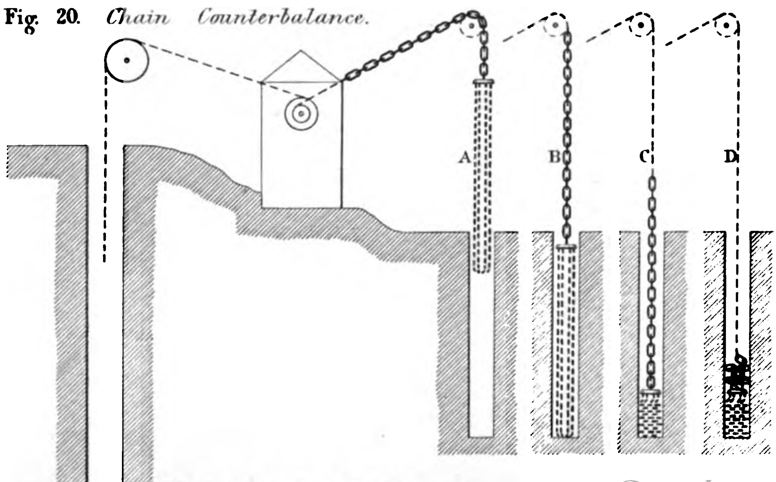


Fig. 20. *Chain Counterbalance.*



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Saw Teeth and Cutters.

Fig. 1. *Soft Wood Saw.*

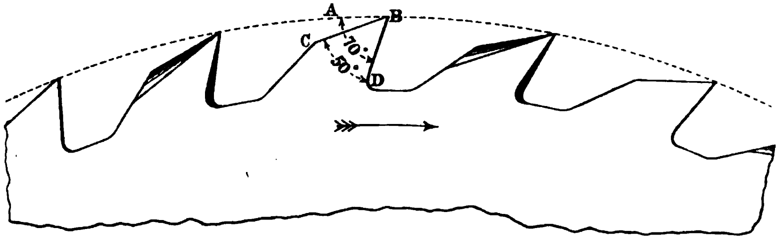


Fig. 2. *Hard Wood Saw.*

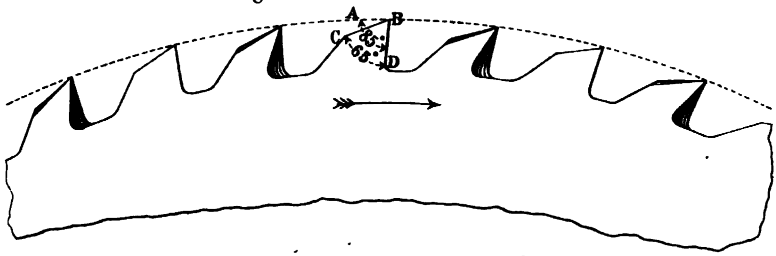


Fig. 3. *Cross-Cutting Saw.*

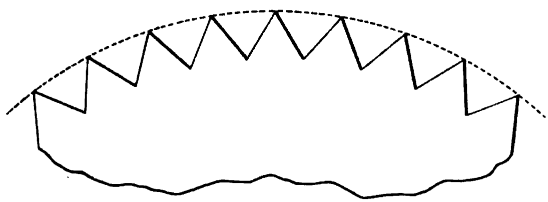


Fig. 4. *Soft Wood Cutter.*

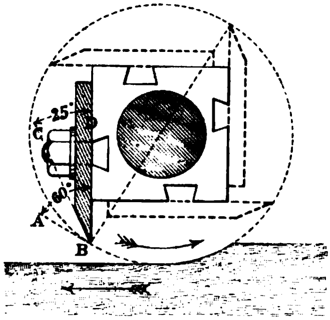
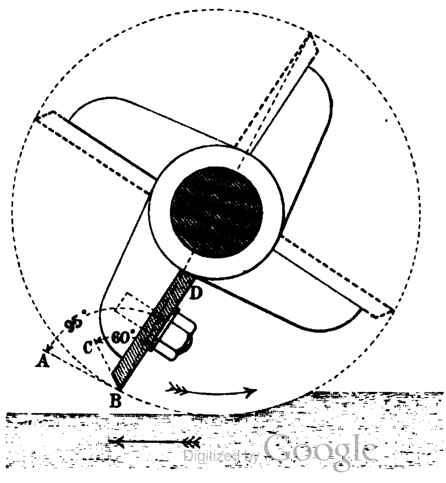


Fig. 5. *Hard Wood Cutter.*



Scale 1/4th.

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WOOD-WORKING MACHINERY.

Tenoning Cutter.

Scale 1/3rd

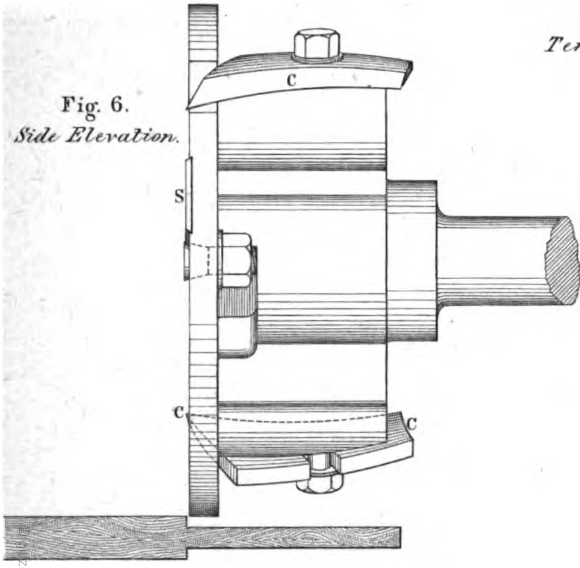

Fig. 6.
Side Elevation.

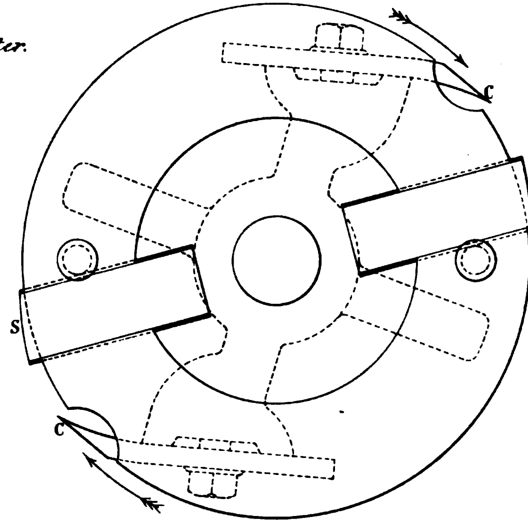

Fig. 7.
Face View.

Fig. 8. *Conical Bearing for Cutter-block Spindles in Planing Machine. Scale 1/2.*

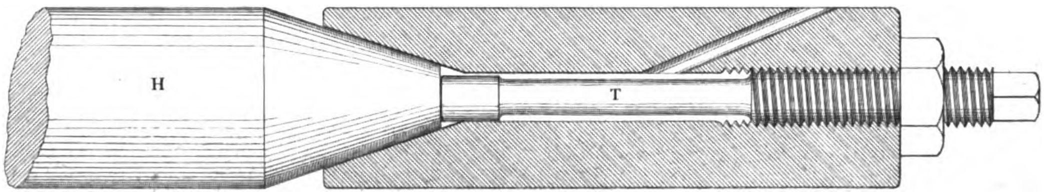

Plate 39.

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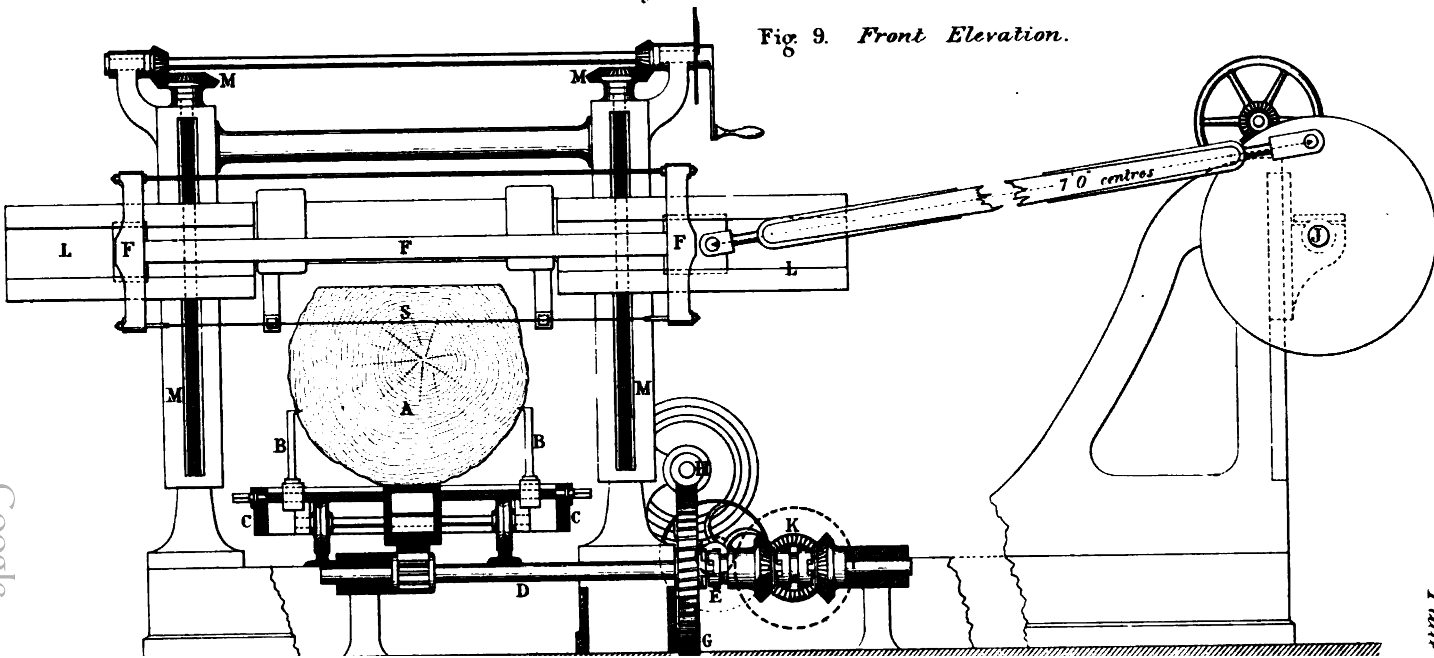
WOOD-WORKING MACHINERY.

Horizontal Single-bladed Saw Frame.

Fig. 9. *Front Elevation.*



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WOOD-WORKING MACHINERY.

Horizontal Single-bladed Saw Frame.

Fig. 10. *Plan.*

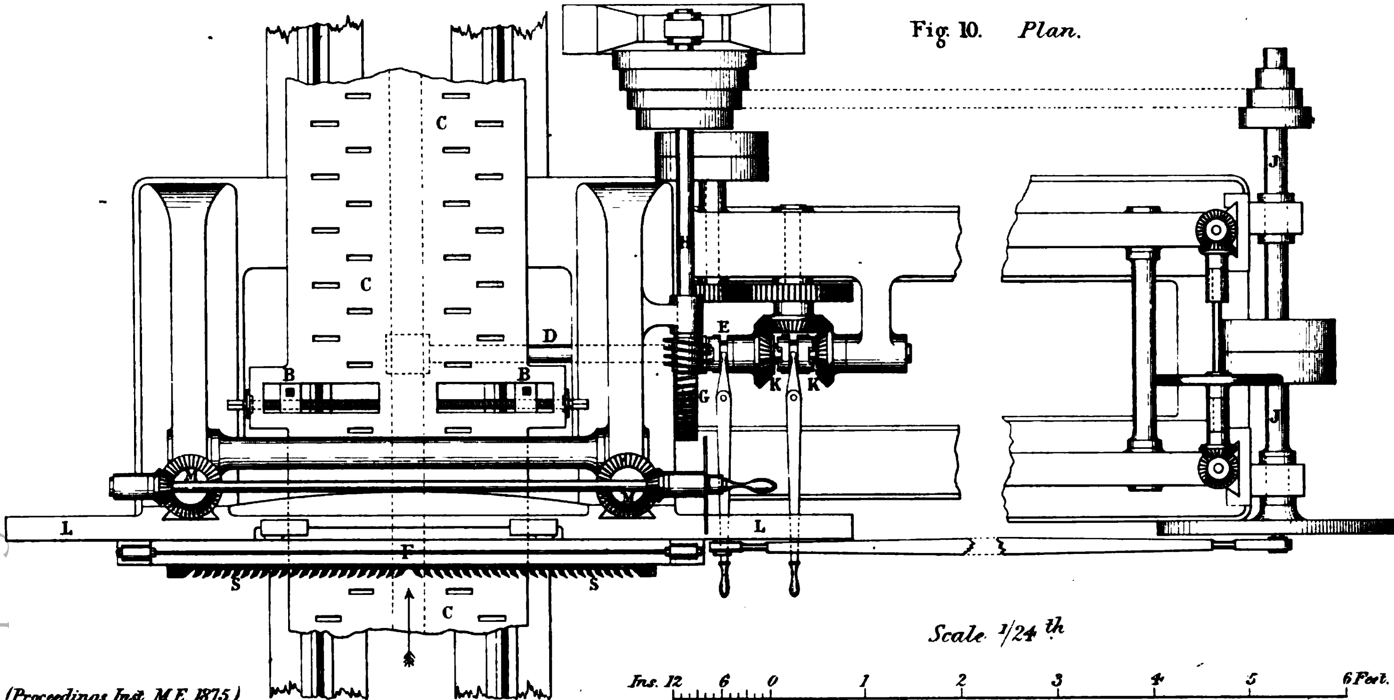

Plate 41.

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Plate 42.

WOOD-WORKING MACHINERY.

Horizontal Single-Bladed Saw Frame.

Fig. 11. Elevation of Saw-Frame and Slides. Scale 1/24th

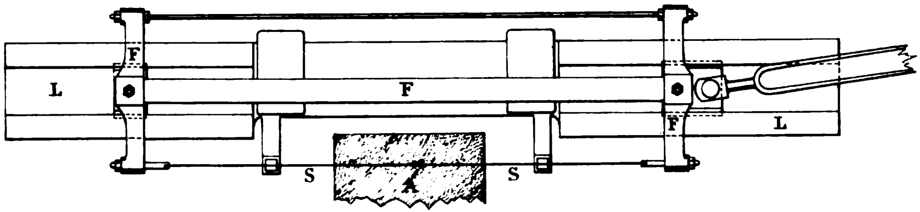


Fig. 12. Plan.

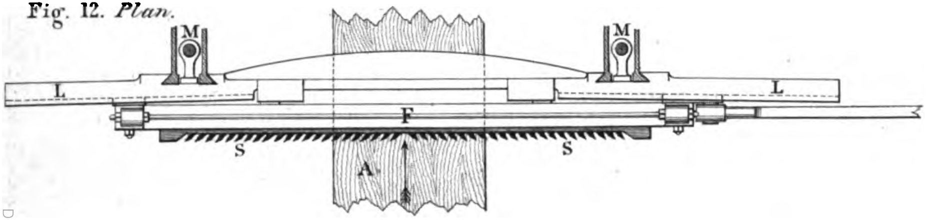
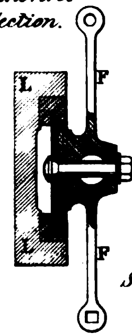


Fig. 13. Transverse Section.

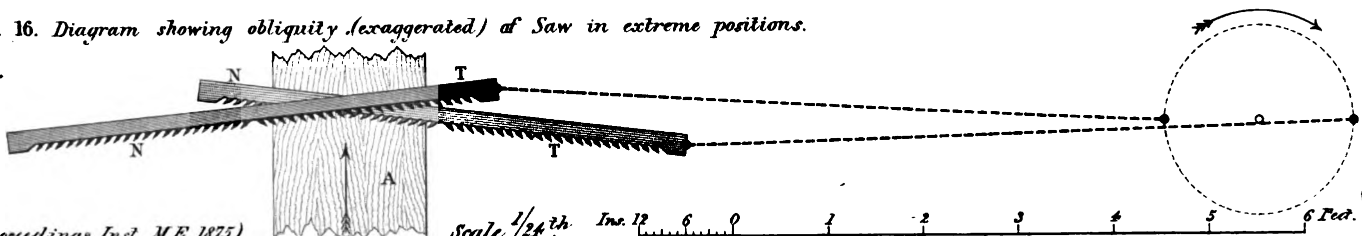


Slide Block.

Fig. 14. Fig. 15.

Scale 1/12th

Fig. 16. Diagram showing obliquity (exaggerated) of Saw in extreme positions.



Scale 1/24th

Plate 42.

(Proceedings Inst. M.E. 1875)

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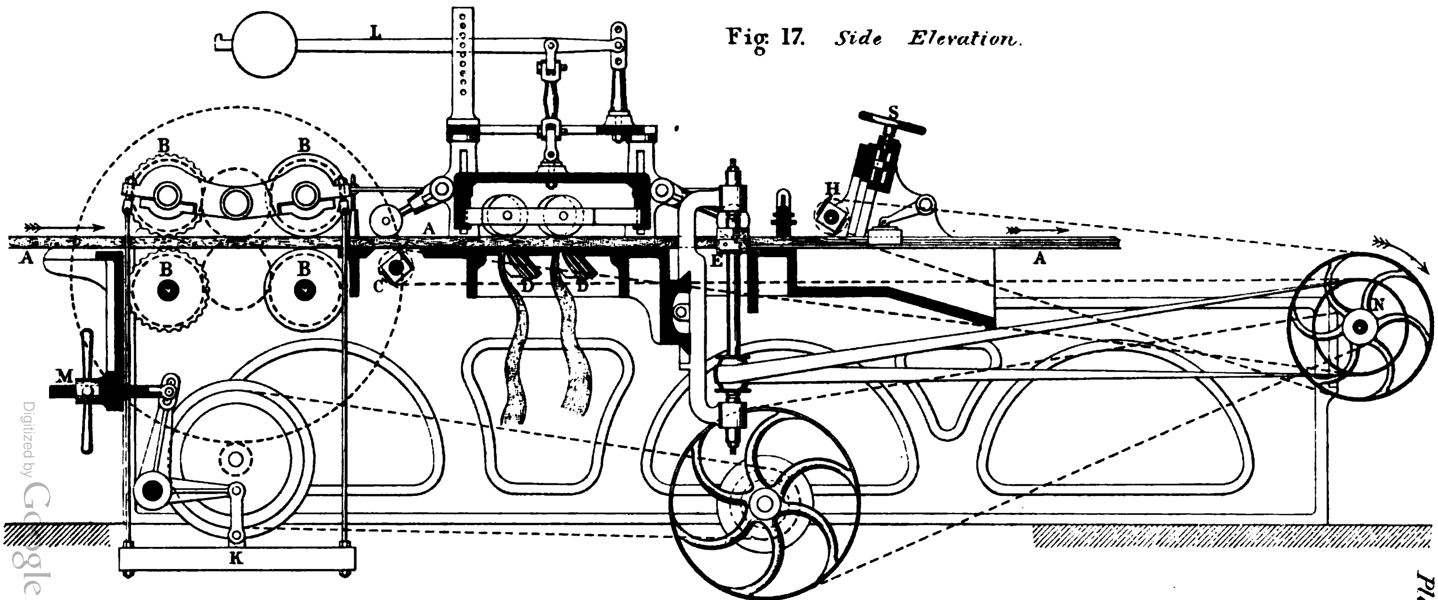
WOOD-WORKING MACHINERY.

Planing and Moulding Machine.

Fig. 17. *Side Elevation.*



Scale 1/24 th

Ins.12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

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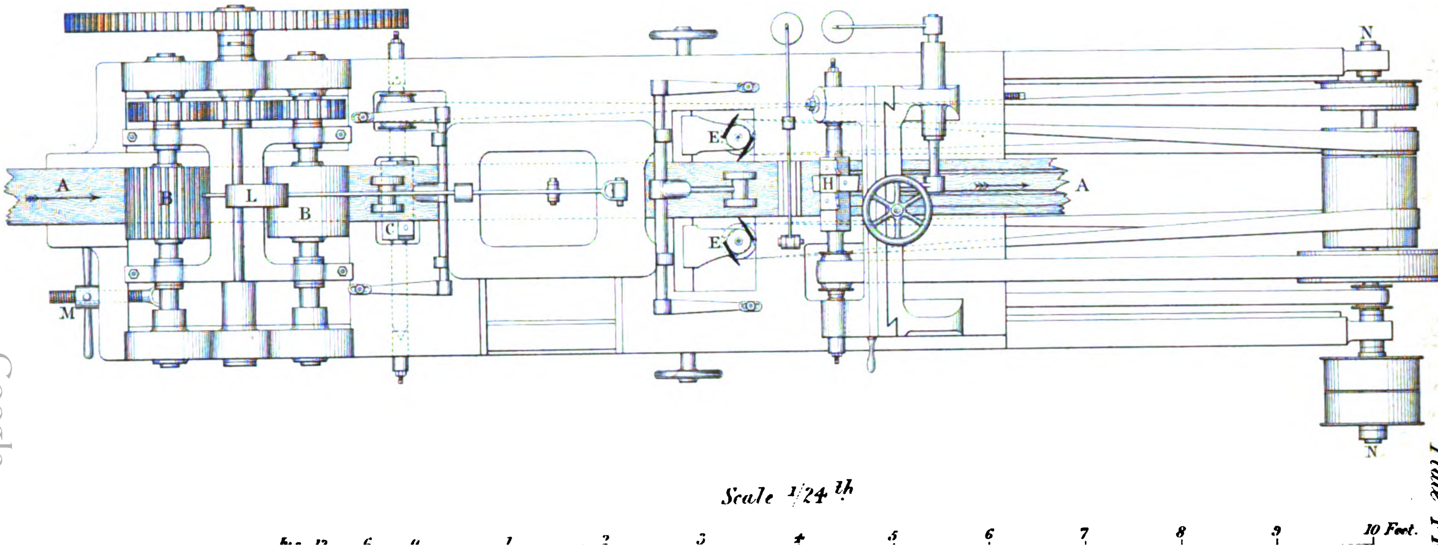
WOOD-WORKING MACHINERY.

Planing and Moulding Machine.

Fig. 18. *Plan.*



Scale 1/24th

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WOOD-WORKING MACHINERY.

Planing and Moulding Machine.

Top Cutter-block and Headstock.

Fig. 19. *Side Elevation.*

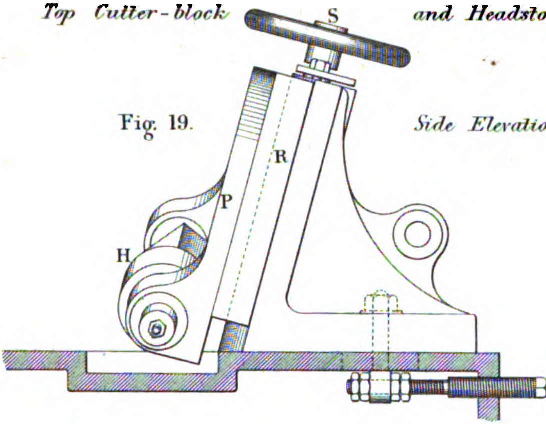


Fig. 20. *Front Elevation.*

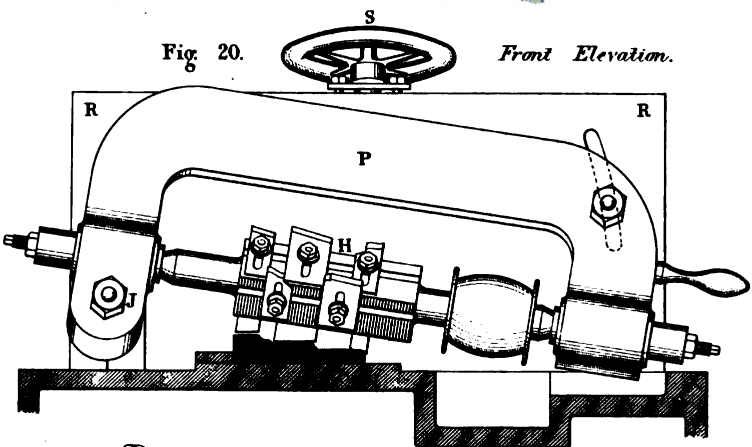
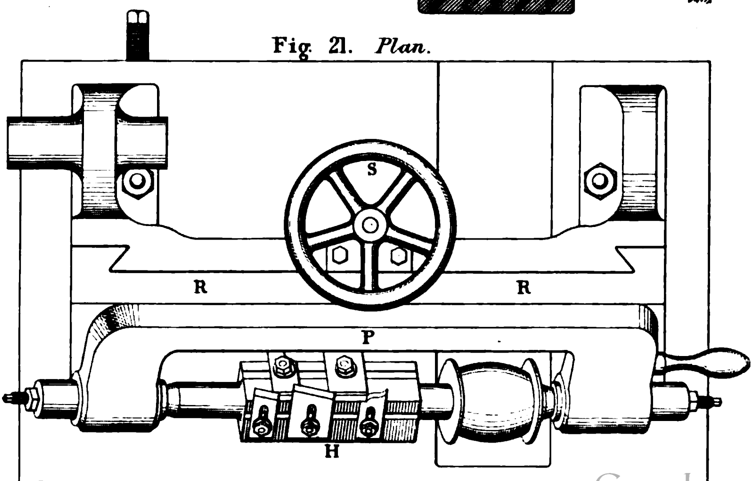


Fig. 21. *Plan.*



 Scale 1/10th 0 5 10 15 20 Ins.

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Mould Box for Compressing Fluid Steel.

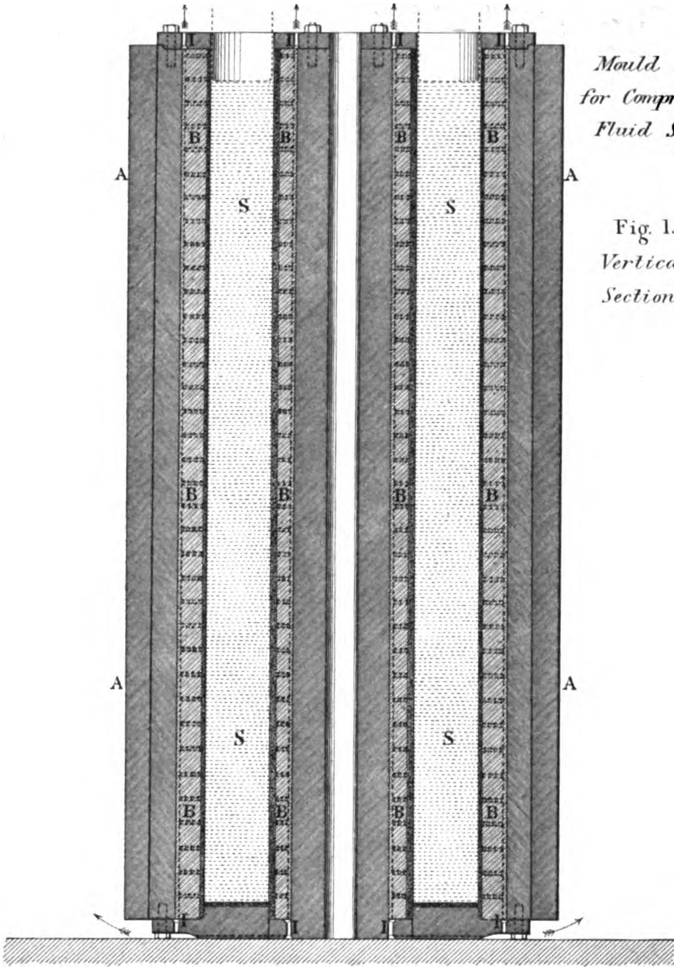

Fig. 1.
Vertical Section.

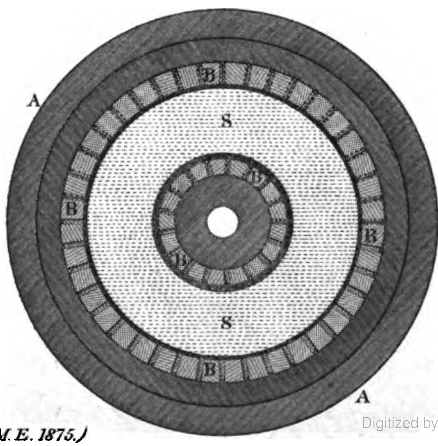

Fig. 2.
Sectional Plan.

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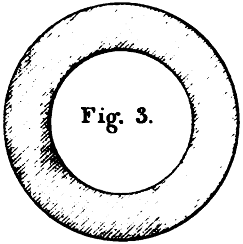
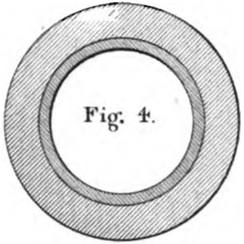
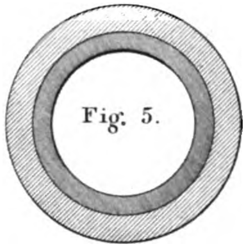
Scale 1/24 th.

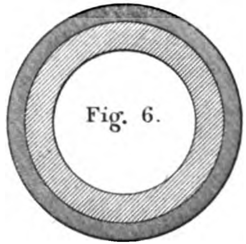
FLUID COMPRESSED STEEL AND GUNS.

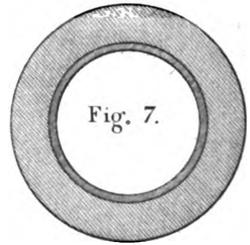
Full-size Transverse Sections of Experimental Cylinders tested by explosion of gunpowder.







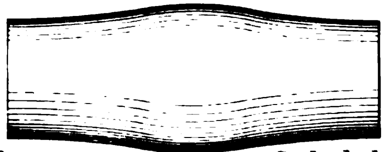




Outside Elevations of Experimental Cylinders.

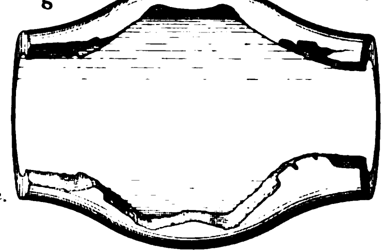
Fig. 8. *Before firing.*

Fig. 9. *After firing a few rounds.*



Scale half full size.

Fig. 10. *Burst.*



Scale half full size.

Cylindrical Bars for Tensile Test.

Fig. 11. *Before testing.*

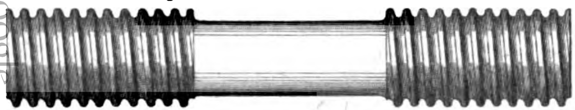
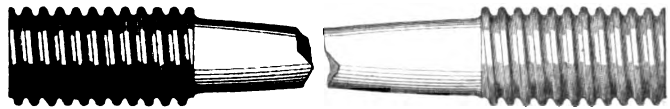


Fig. 12. *After pulling asunder.*



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Scale half full size.

Plate 47.

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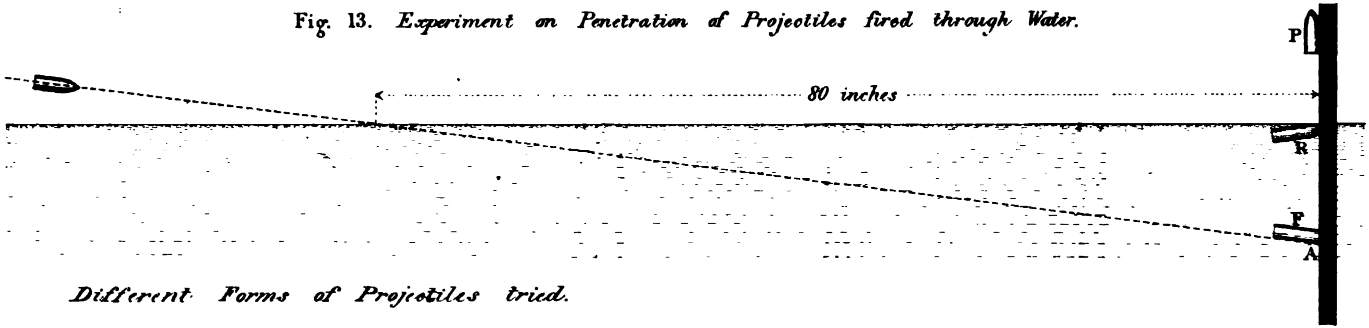
FLUID COMPRESSED STEEL AND GUNS.

Fig. 13. *Experiment on Penetration of Projectiles fired through Water.*



Different Forms of Projectiles tried.

Fig. 15.

Fig. 16.

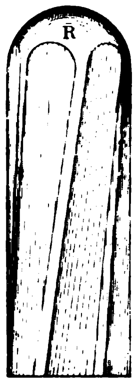


Fig. 17.

Fig. 18. *Transverse Section.*

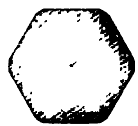
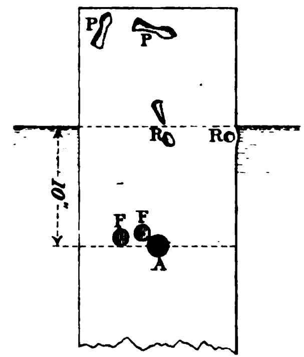


Fig. 14. *Target.*



(*Proceedings Inst. M. E. 1875.*)

Scale half full size.

Scale 1/16th.

Plate 48.

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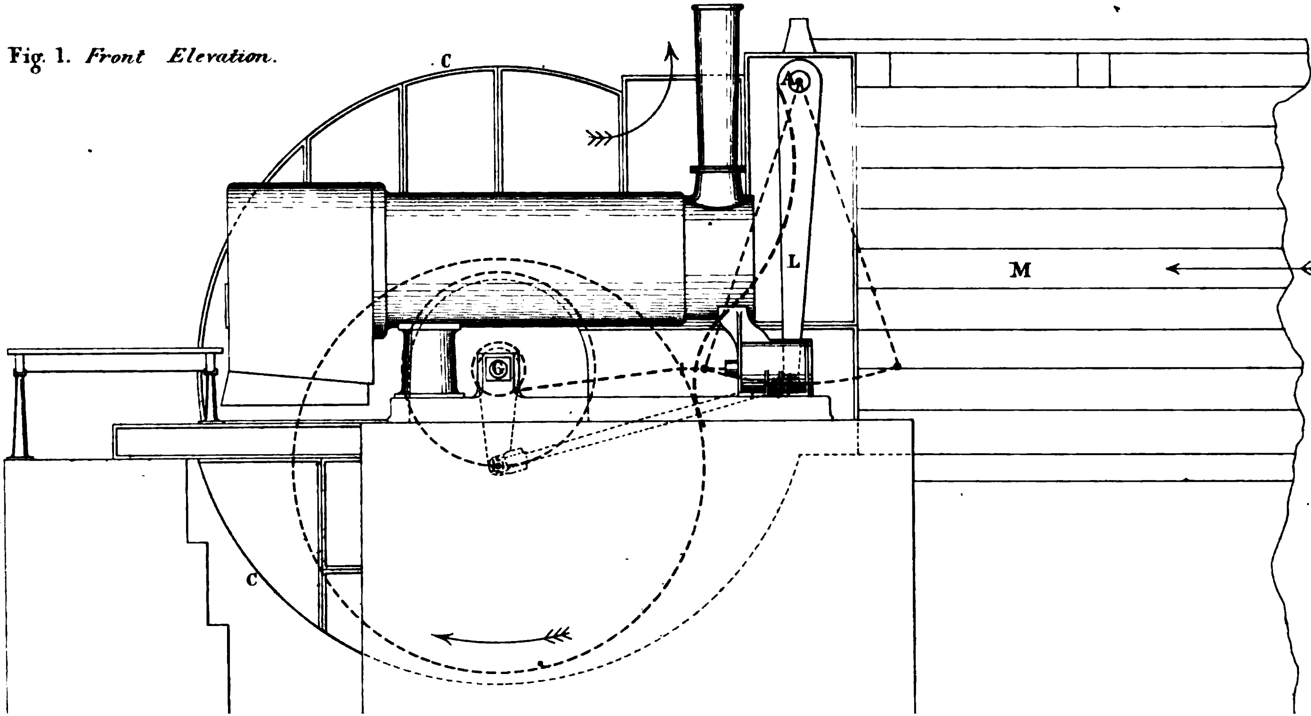
MECHANICAL VENTILATORS FOR MINES. Plate 49.

Cooke's Ventilator.

Fig. 1. *Front Elevation.*



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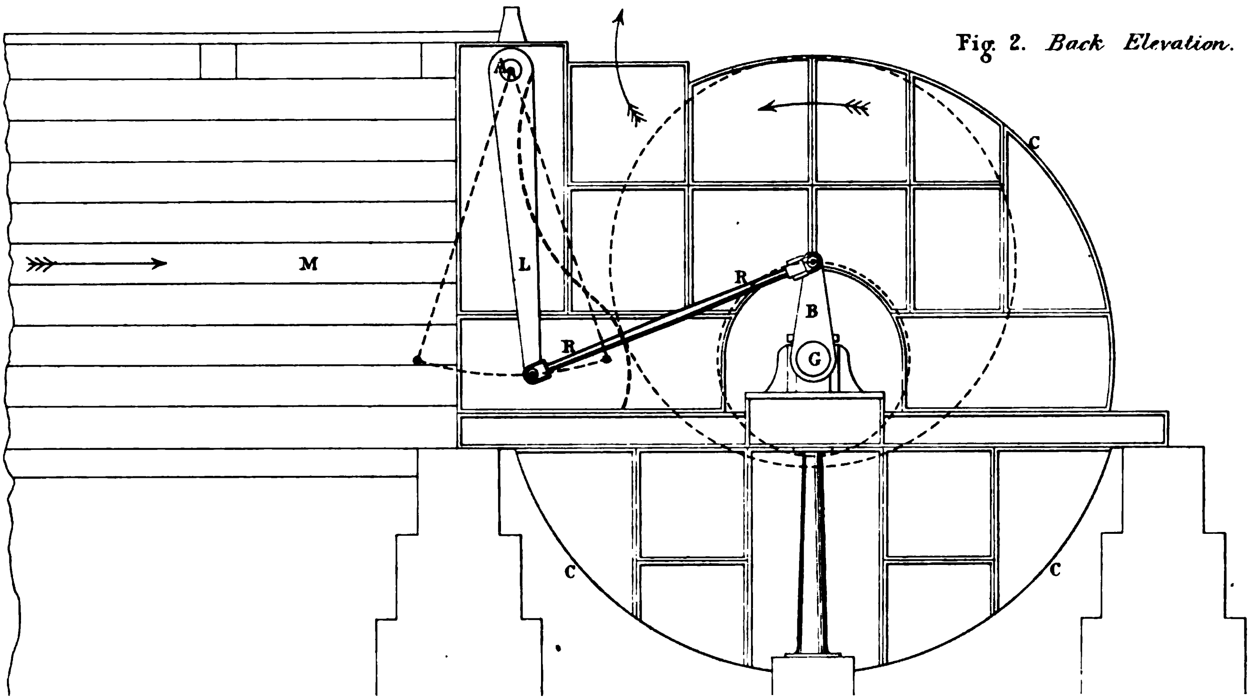
MECHANICAL VENTILATORS FOR MINES.

Cooke's Ventilator.

Fig. 2. *Back Elevation.*



Plate

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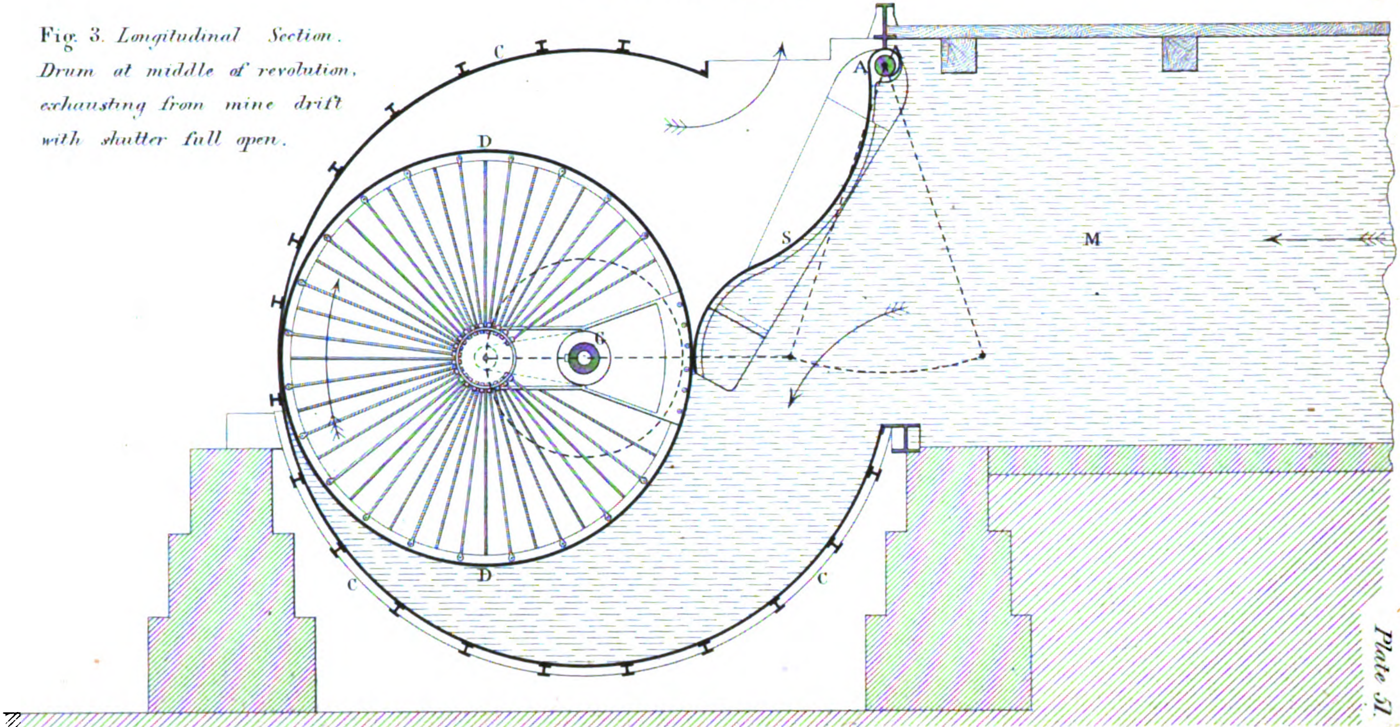
MECHANICAL VENTILATORS FOR MINES.

Cooke's Ventilator.

Fig. 3. Longitudinal Section.
Drum at middle of revolution, exhausting from mine drift with shutter full open.



Scale 1/80 th

0 5 10 15 20 25 Feet.

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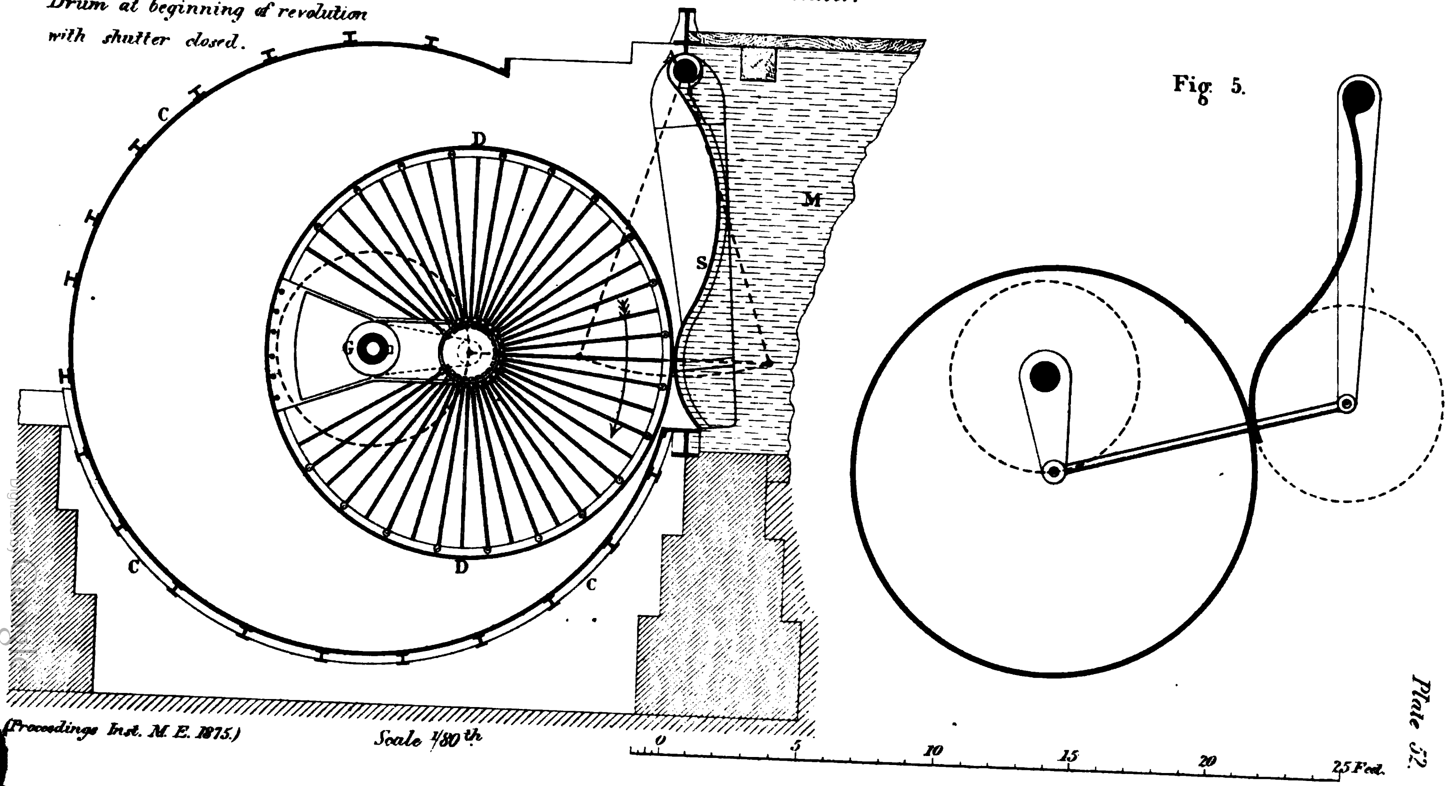
MECHANICAL VENTILATORS FOR MINES.

Cooke's Ventilator.

Fig. 4. *Longitudinal Section.*
Drum at beginning of revolution
with shutter closed.

Fig. 5.



Scale 1/80th.

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Plate 52.

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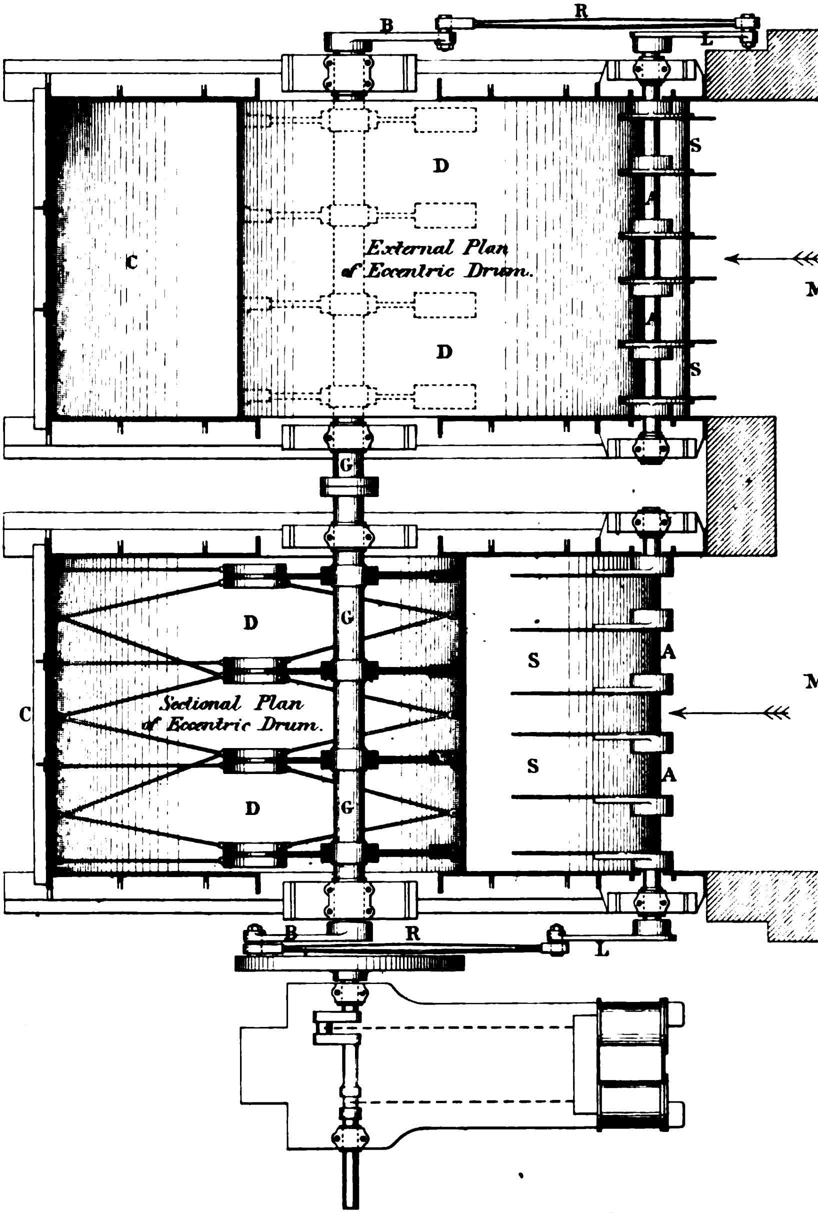
MECHANICAL VENTILATORS FOR MINES. *Plate 53.*

Cooke's Ventilator.

Fig. 6. *Sectional Plan of pair of Ventilators.*



(Proceedings Inst. M. E. 1875.)

Scale 1/80 th.

0 5 10 15 20 25 Feet

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MECHANICAL VENTILATORS FOR MINES. *Plate 54.*

Indicator Diagrams from Engines driving Ventilators.

Fig. 7. *Cooke's Ventilator at Lofthouse Iron Mines.*

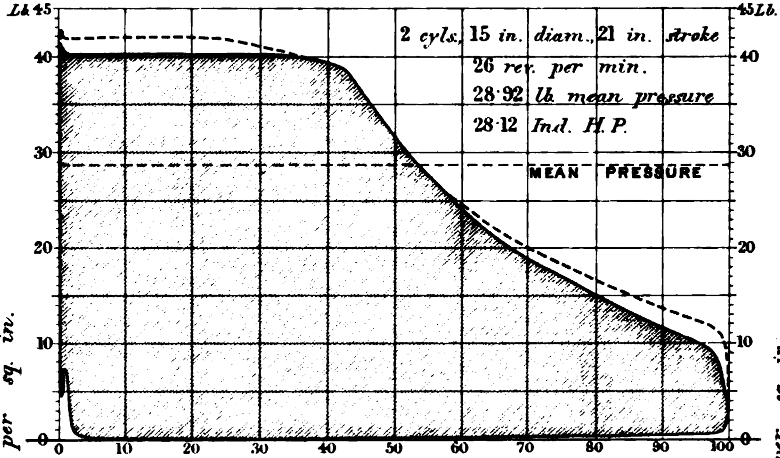
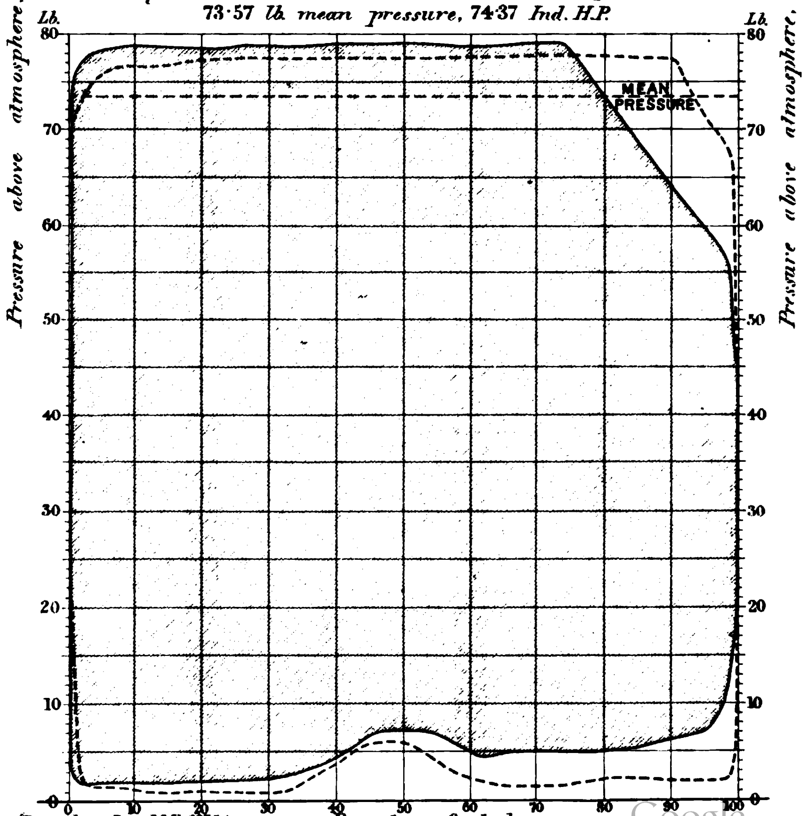


Fig. 8. *Cooke's Ventilator at Upleatham Iron Mines.*
2 *cyls.,* 15 *in. diam.,* 21 *in. stroke,* 26·95 *rev. per min.*
73·57 *lb. mean pressure,* 74·37 *Ind. H.P.*



(Proceedings Inst. M.E. 1875.)

Percentage of stroke.

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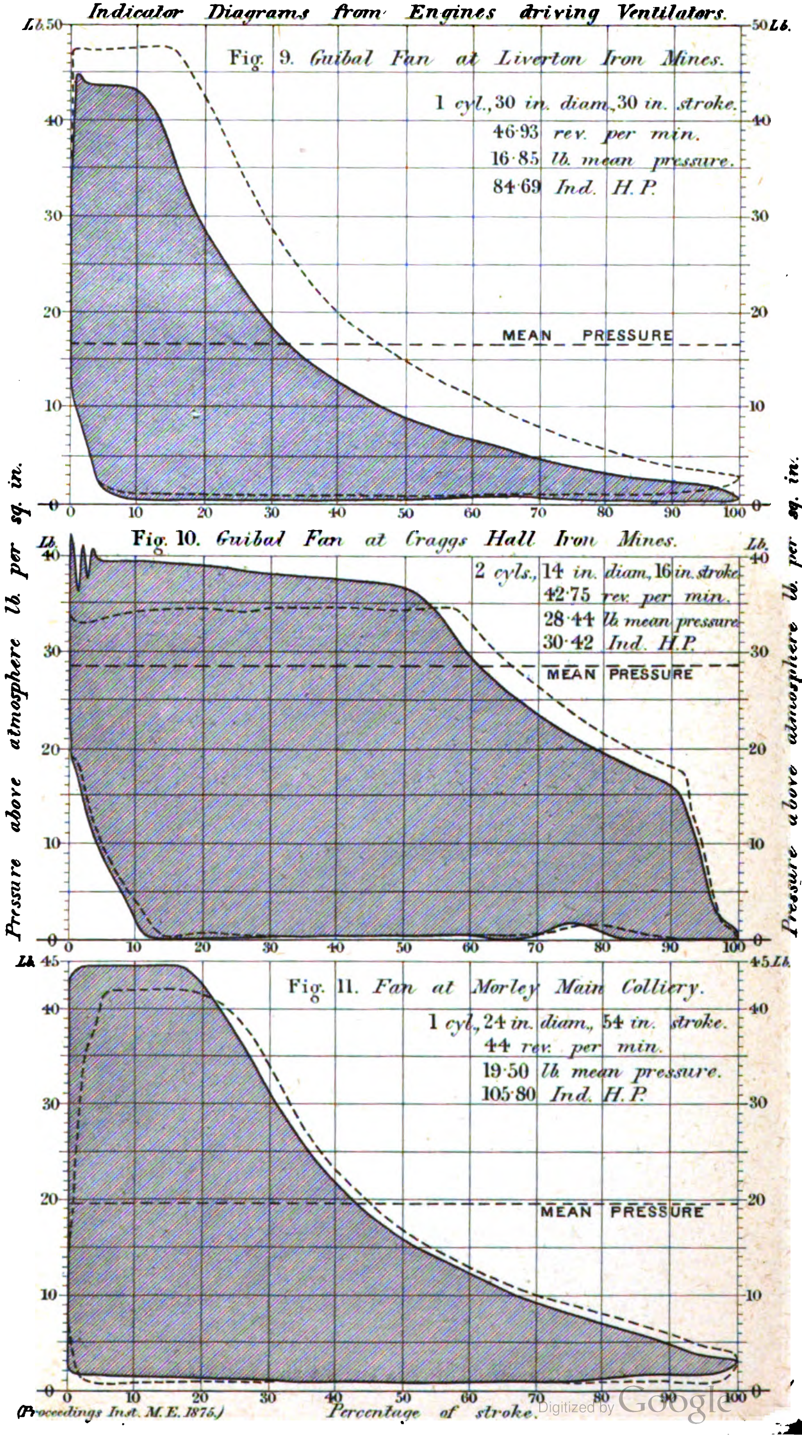
Indicator Diagrams from Engines driving Ventilators.



(Proceedings Inst. M. E. 1875.)

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MECHANICAL VENTILATORS FOR MINES.

Sections of Mine Drifts, showing positions of Anemometer in experiments for measuring Air currents.

Fig. 12. *Upleatham.*

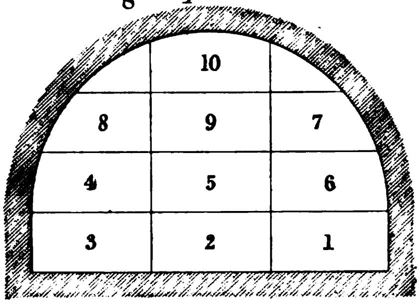


Fig. 13. *Lofthouse.*

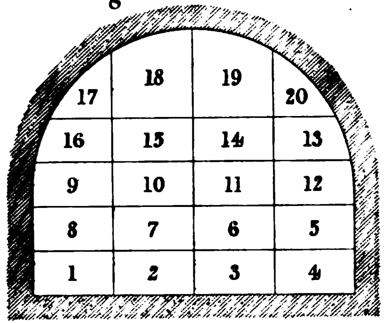


Fig. 14. *Aberaman.*

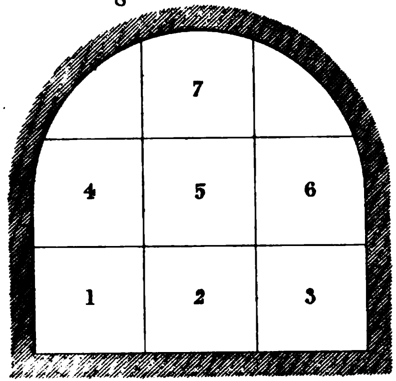


Fig. 15. *Hilda.*

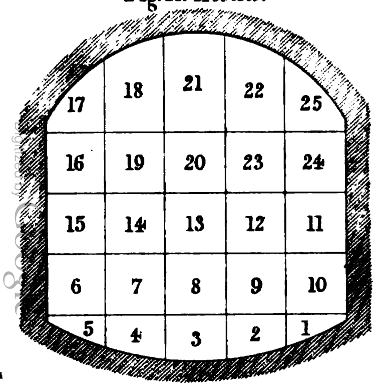


Fig. 16. *Morley Main.*

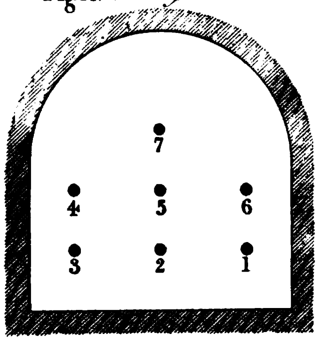


Fig. 17. *Liverton.*

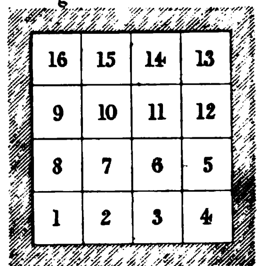
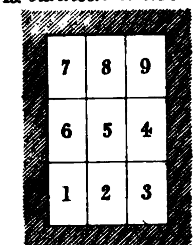


Fig. 18. *Cannock Chase.*



(Proceedings Inst. M. E. 1875)

Scale 1/100th

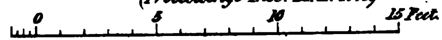
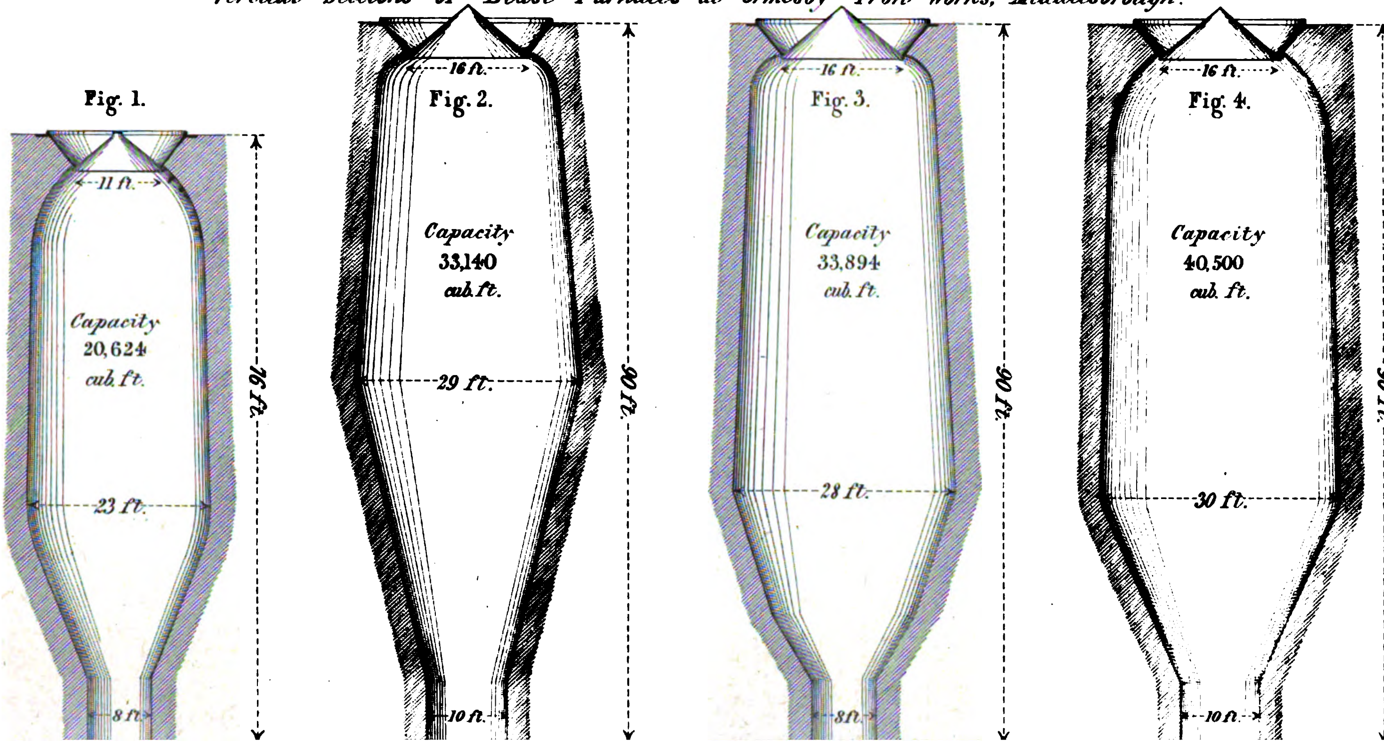


Plate 56.

Plate 57.

ULTIMATE CAPACITY OF BLAST FURNACES.

Vertical Sections of Blast Furnaces at Ormesby Iron Works, Middlesbrough.



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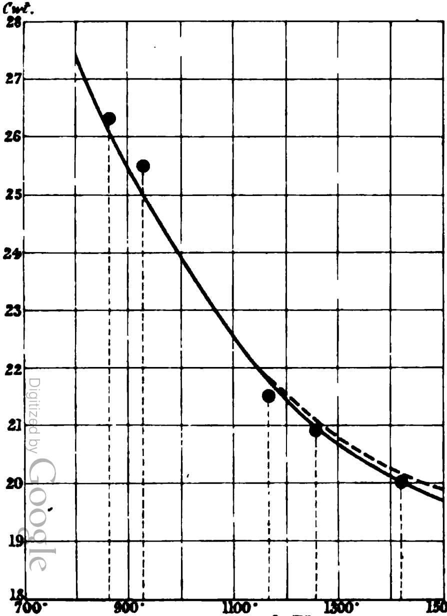
ULTIMATE CAPACITY OF BLAST FURNACES.

Curves showing Economy of Fuel from increased Temperature of Blast in Furnaces at Ormesby Iron Works, Middlesbrough.

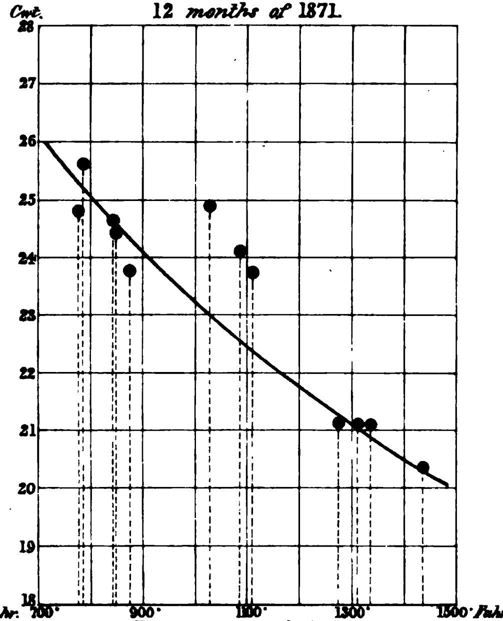
Consumption of Coke per ton of iron made.

Fig. 5.
Furnace 20,624 *cub. ft.*



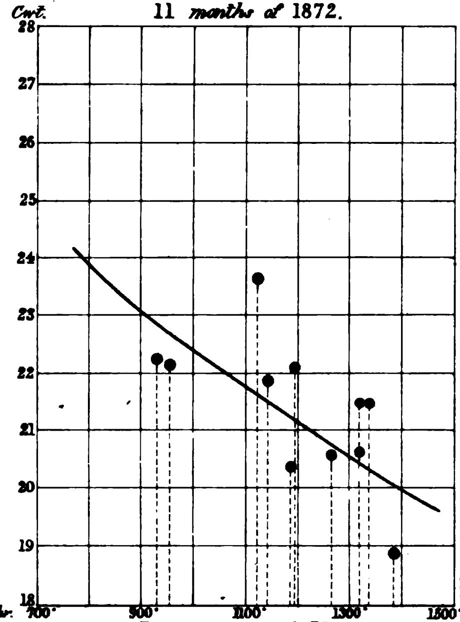
Temperature of Blast.
(Proceedings Inst. M. E. 1875)

Fig. 6.
Furnace 40,500 *cub. ft.*
12 *months of* 1871.



Temperature of Blast.

Fig. 7.
Furnace 40,500 *cub. ft.*
11 *months of* 1872.



Temperature of Blast.

Plate 58.

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ULTIMATE CAPACITY OF BLAST FURNACES.

Fig. 8. *Curves showing Economy of Fuel from increased Capacity of Blast Furnace at Ormesby Iron Works, Middlesbrough.*

Consumption of Coke per ton of iron made with different temperatures of Blast.

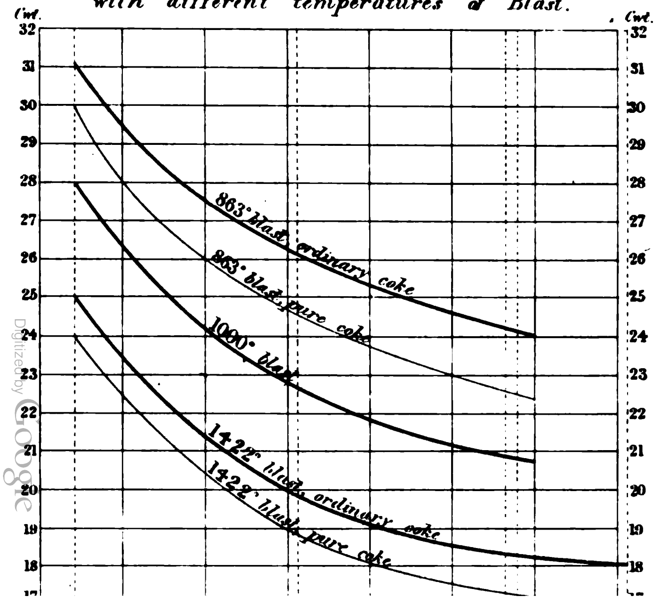
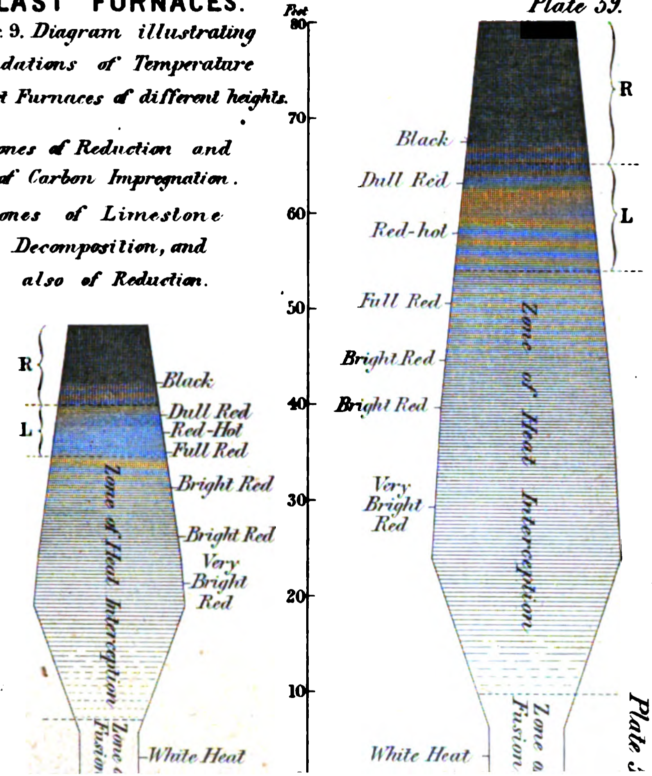


Fig. 9. *Diagram illustrating gradations of Temperature in Blast Furnaces of different heights.*

R - *Zones of Reduction and of Carbon Impregnation.*

L - *Zones of Limestone Decomposition, and also of Reduction.*



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MECHANICAL VENTILATORS FOR MINES.

Sections of Mine Drifts, showing positions of Anemometer in experiments for measuring Air currents.

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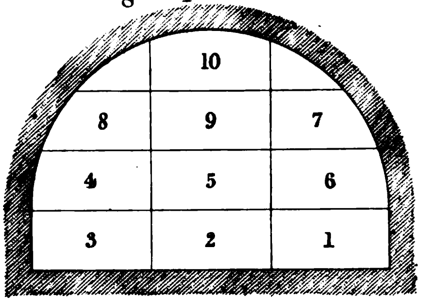


Fig. 13. *Lofthouse.*

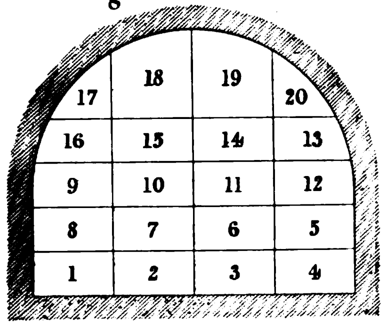


Fig. 14. *Aberaman.*

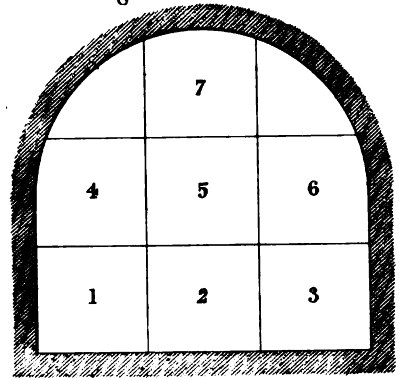


Fig. 15. *Hilda.*

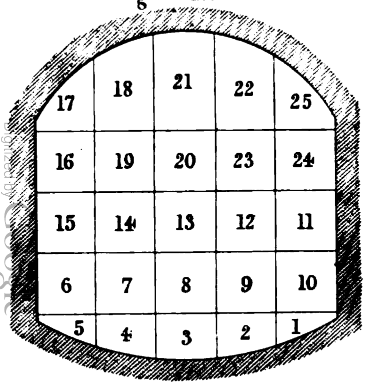


Fig. 16. *Morley Main.*

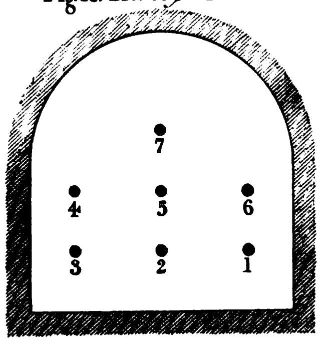


Fig. 17. *Liverton.*

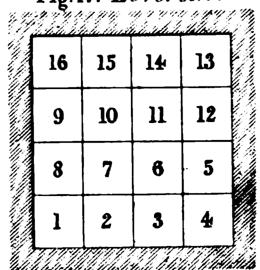
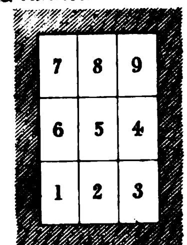


Fig. 18. *Cannock Chase.*



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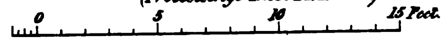
Scale 1/100th.



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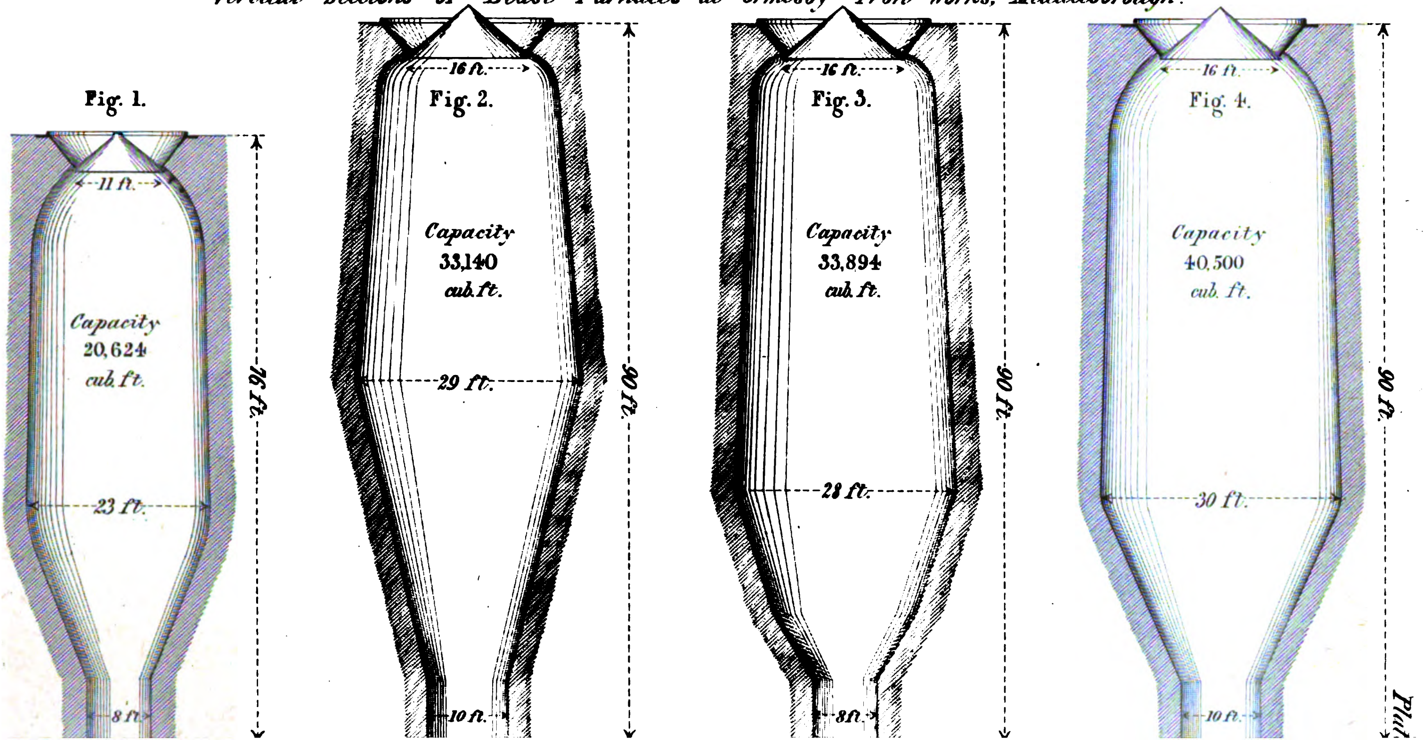
ULTIMATE CAPACITY OF BLAST FURNACES.

Vertical Sections of Blast Furnaces at Ormesby Iron Works, Middlesbrough.



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ULTIMATE CAPACITY OF BLAST FURNACES.

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Consumption of Coke per ton of iron made.

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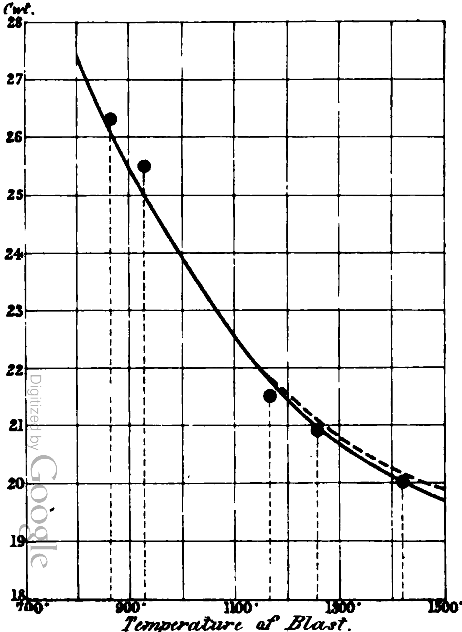

Fig. 6.
Furnace 40,500 *cub. ft.*
12 *months of* 1871.

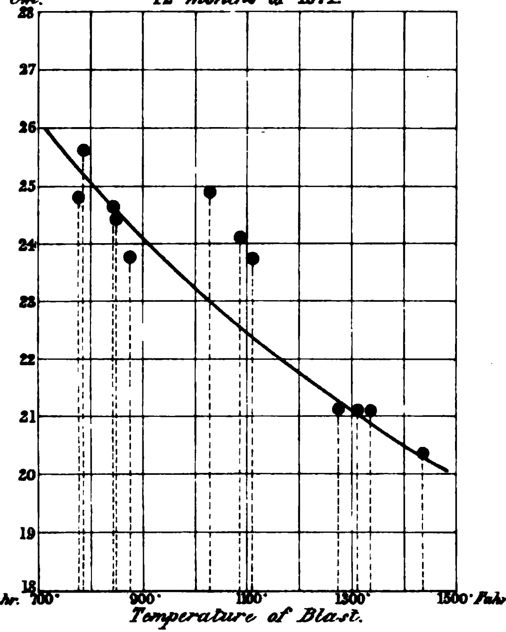

Fig. 7.
Furnace 40,500 *cub. ft.*
11 *months of* 1872.

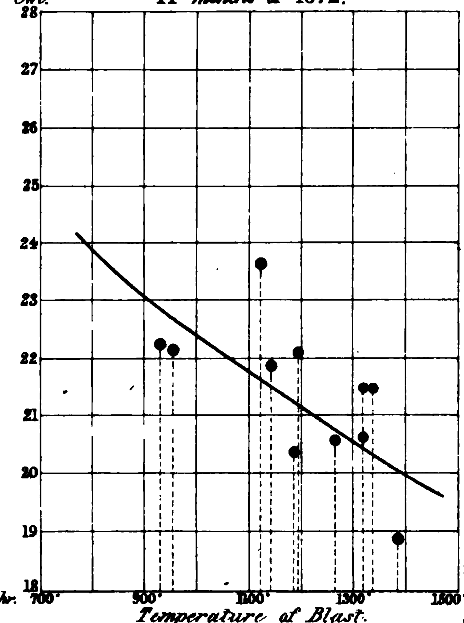

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Plate 58.

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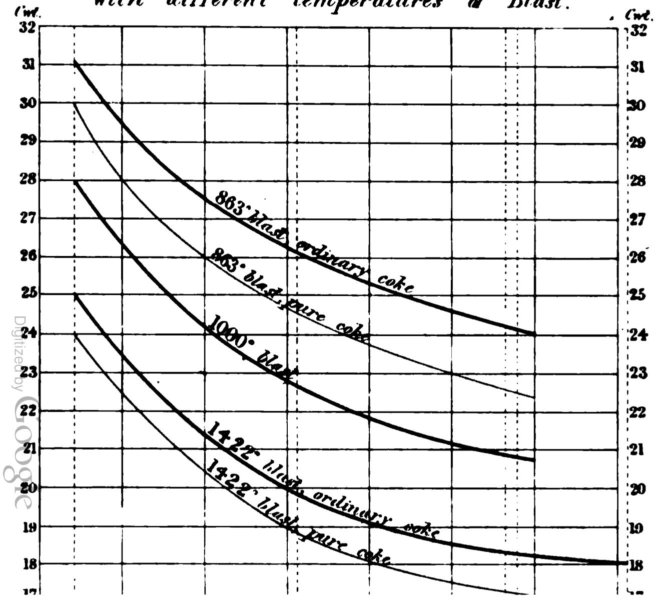
ULTIMATE CAPACITY OF BLAST FURNACES.

Fig. 8. *Curves showing Economy of Fuel from increased Capacity of Blast Furnace at Ormesby Iron Works, Middlesbrough.*

Consumption of Coke per ton of iron made with different temperatures of Blast.



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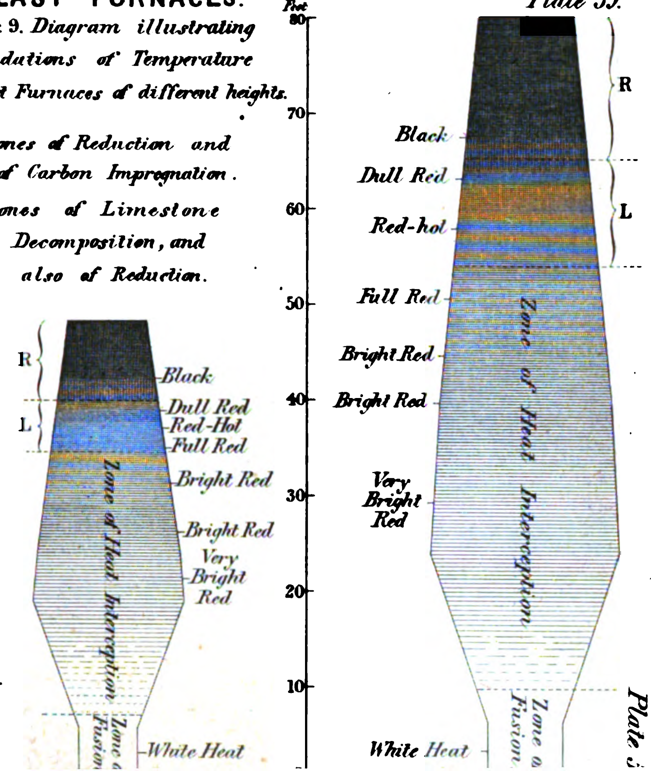

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